HFL-81-1/NPRDC-81-1 1 March 1981

EFFECTS OF SYSTEM TIMING PARAMETERS ON OPERATOR PERFORMANCE IN A PERSONNEL RECORDS TASK

Robert C. Williges
Beverly H. Williges

Virginia Polytechnic Institute
and State University
Blacksburg, Virginia 24061

FINAL TECHNICAL REPORT
CONTRACT NO. N00123-80-C-0300

Principal Investigator
Robert C. Williges

Navy Personnel Research and Development Center
San Diego, California 92152

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A779290
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) EFFECTS OF SYSTEM TIMING PARAMETERS ON OPERATOR PERFORMANCE IN A PERSONNEL RECORDS TASK	5. TYPE OF REPORT & PERIOD COVERED Final Technical Report
	6. PERFORMING ORG. REPORT NUMBER HFL-81-1/NPRDC-81-1
7. AUTHOR(s) Robert C. Williges Beverly H. Williges	8. CONTRACT OR GRANT NUMBER(s) N00123-80-C-0300
9. PERFORMING ORGANIZATION NAME AND ADDRESS Virginia Polytechnic Institute & State University Blacksburg, VA 24061	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Code 302 Navy Personnel Research & Development Center San Diego, CA 92152	12. REPORT DATE March 1981
	13. NUMBER OF PAGES 86
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

human-computer interface, data entry, personnel records, operator performance measurement, automated performance assessment, display rate, system response time, keyboard echo rate, keyboard buffer length, central-composite design, response surface, polynomial regression

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Meaningful human factors applications to the design of human/computer tasks require a quantitative data base that describes operator behavior as a function of various independent variables. Three classes of metrics including operator satisfaction ratings, work sampling procedures, and embedded performance measurement are described as important measures in evaluating human/computer interfaces. Polynomial regression procedures were used to generate functional relationships between each of these metrics and four independent variables representing —

20. ABSTRACT

timing attributes of an interactive computer system used to enter and update personnel records. The four timing attributes included system delay, display rate, keyboard echo rate, and rollover buffer length of the keyboard. Each of the 22 dependent variables in the three classes of metrics showed different functional relationships among the four system variables, but overall system delay and keyboard echo rate were the major predictors of operator behavior. Additionally, the three classes of metrics were combined into three underlying interface dimensions relating to operator production, waiting, and planning activities.

ACKNOWLEDGEMENTS

This research was conducted as part of a research program supported by the Navy Personnel Research and Development Center under contract number N00123-80-C-0300. The opinions expressed in this paper, however, are those of the authors and are not intended to represent official Navy views. Mr. Richard W. Obermayer and Mr. John Malone served as contract monitors and provided many valuable suggestions throughout the conduct of this research. Several individuals at the Virginia Polytechnic Institute and State University Human Factors Laboratory contributed to this effort. Software support for the generation of the generic task simulation was provided by John E. Evans, III. Jay A. Pittman and Sidney A. Connors also assisted in the data collection phases of this work. Their individual and combined contributions are gratefully acknowledged.

SUMMARY

Problem

Navy personnel records are becoming more computerized, and design of the human/computer interface must be considered in order to increase data entry productivity as well as reduce entry errors. To enhance these design considerations, functional relationships of operator performance are needed which incorporate a variety of system, task, operator, and environmental factors.

Objective

The purpose of this study is to demonstrate the utility of using three classes of metrics, including work sampling, embedded performance measures, and satisfaction ratings, to evaluate the human/computer interface for data entry of personnel records. Each class of measures was used to generate functional relationships between operator performance and four system parameters including system response time, display rate, keyboard echo rate, and keyboard buffer length.

Method

A simulated data entry task was structured around a Navy personnel records task in which the operator was required to use an interactive computer terminal to perform either ADD or CHANGE transactions on simulated pay order records. An orthogonal, central-composite design was used to specify the data collection

requirements for evaluating the four system timing variables. A total of 400 transactions were evaluated across 22 different dependent variables representing the three classes of metrics evaluated in this study.

Results

Both univariate and multivariate analyses were conducted on the data in order to generate a series of second-order polynomial regression equations. The univariate polynomial regression equations described the functional relationships between the four system timing variables for each of the 22 separate dependent variables. The most important variables included time spent looking at the display, time spent looking at the keyboard while typing, typing rate, and overall operator satisfaction. The multivariate polynomial regression analyses provided functional relationships in terms of three composite measures representing production, waiting, and planning activities of the operator. Although all four system variables were significant in various evaluations, the most important system timing variables across all analyses were the system response time and keyboard echo rates.

Conclusions

All three classes of metrics (i.e., work sampling, embedded performance measures, and operator satisfaction ratings) are needed to provide a complete analysis of the effects of the four system variables on operator behavior. By using these three classes of measures and representing the functional relationships in terms of response surfaces, the system designer can easily superimpose the various surfaces to make the necessary human/computer interface design tradeoffs. Additionally, a more general interpretation of the human/computer interface can be made by using multivariate response surfaces representing operator production, waiting, and planning activities.

Recommendation

Additional research is needed to validate the three general multivariate activities which characterized the human/computer interface in this personnel records task. A variety of other human/computer interface tasks need to be evaluated by this procedure to investigate the robustness of these dimensions as well as the differential weightings of these dimensions across tasks.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Problem

Navy personnel records are becoming more computerized both to increase the productivity of personnelmen who enter and update records and to reduce the number of data entry errors. Two current Navy systems, the Manpower and Personnel Information System (MAPMIS) and the Joint Uniform Military Pay System (JUMPS), are extremely large scale information management systems that receive widespread, distributed entry from over 3000 field offices. Source data entry to each system is extremely labor intensive; it has been estimated that approximately 25% of the time of individuals holding personnelman ratings in Navy personnel offices is devoted to data input to MAPMIS and JUMPS (Michna, Laidlaw, and Obermayer, 1978).

In addition to the investment of large amounts of personnel hours, Obermayer (1977) cites two other critical problem areas. These include significant error rates (10-30%) and long delays (70-90 days) in updating personnel information entered by hand-typed optical character recognition forms (OCR). Significant improvements in all of these areas are feasible through various office automation procedures involving direct human/computer interface. Care, however, must be taken to consider appropriate human engineering design principles to optimize the human/computer communication interface. The magnitude of this design problem was recently underscored by a GAO report (1980) which evaluated various inefficiencies in the Navy's computerized pay system.

Background

Even though the fundamental concept of an interactive system requires a continual interaction between the human and the computer, few data exist on the operation of the system hardware and operator behavior. Although each system is somewhat unique, any on-line interaction with time-sharing systems involves several factors. Carbonell, Elkind, and Nickerson (1968) discussed the parameters of accessibility and response time. Accessibility is the ability of the user to enter the time-sharing system and is a function of the current load. Clearly, the ideal situation would be a time-sharing system that is always accessible when the user wants it. But, this ideal state is often not realized and no data exist on the effect of limited accessibility on user rates.

Response time, on the other hand, is the amount of time required by the system to respond to a user input and depends on a variety of factors including the current number of users, the complexity of the calculation necessitated by the user input, and the hardware configuration of the system. If the response time of an interactive system is not adequate, the human's performance may deteriorate. Obviously, there is no one optimum response time that pertains to all time-sharing situations. In fact, Engel and Granda (1975) present guidelines ranging from 0.1 seconds to 60 seconds maximum acceptable response time depending upon the system recognized activity (e.g., key response, file update, error feedback) and user activity (e.g., system activation, loading and restart). Generally, the recommended guideline for system acknowledgment that a request is being processed is an almost instantaneous response time i.e., <0.5 seconds). Miller (1968), for example, recommends that all other human/computer interactions should have less than a 2 second response time unless the operator is engaged in the particular terminal operation only infrequently.

Actual behavioral data of the effect of system response time are quite limited. Morfield, Wiesen, Grossberg, and Yntema (1969) studied the effect of response times varying from 1 second to 100 seconds on user problem solving performance. Average time to completion increased as expected, but net completion time also increased which suggested that the operator was becoming distracted. Additional research by Grossberg, Wiesen, and Yntema (1976) introduced unknown variability into the various response times. This research showed that although users made fewer inquiries of the time-sharing systems with longer system response times, system delays did not affect their actual time to solution.

One particularly critical issue relating to the effects of system response on operator performance is that much of the previous research is not directed toward true system-related variables manipulated within realistic operational ranges. The current data collection effort on this project provided some meaningful information in this regard. Specifically, variables such as the display rate, delays in displaying echoing of keyboard inputs, and the design variables that vary quite markedly in existing time-sharing systems. Essentially no data are available on the separate and combined effects of these variables on operator behavior. System and display design decisions are constantly being made devoid of these data even though the human operator is the ultimate user of the interactive system.

A preliminary study by Beatty and Williges (1980) provided the background data for the current study. Their results suggested that embedded measures of the operator's data entry performance can be used as powerful tools in measuring the human/computer interface. In this regard, both user ready time and system response times need to be evaluated in complicated tasks involving personnel transactions.

A more comprehensive approach is needed where a variety of actual system, task, operator, and environment independent variables are manipulated together and their functional relationship to operator/analyst performance is described. With the inherent automatic data recording capabilities of computer-based systems, this approach seems feasible. Finkelman, Wolf, and Friend (1977) offer polynomial regression as a reasonable method to define such functional relationships for data characterized by lower-order trends. A polynomial expression provides a convenient approximation to a variety of mathematical relationships thereby making it a powerful tool for predicting operator performance while still using a standard format. The general form of such a second-order polynomial model would be,

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{k+i} X_i^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} \beta_{2k+i} X_i X_j + \varepsilon, \quad (1)$$

where human behavior Y, is expressed in terms of an intercept value β_0 , and the weighted linear combinations of first-order terms, X_i , pure quadratic second-order terms, X_i^2 , and linear interaction, second-order terms, $X_i X_j$, of the k system variables stated in terms of X_is. The value ε is the estimate of error in prediction. Sample estimates, b, of the various β parameters are readily obtained through standard least square regression procedures.

Recently, Williges (1977) suggested that this polynomial regression approach would be useful in developing an automated assessment scheme of personnel performance in computer-based systems. This performance scheme, in turn, could be used for embedded performance measurement, evolutionary system operation, performance enhancement procedures, and the development of realistic data bases from which theoretical extrapolations can be made to the design of future human/computer systems.

In addition to specifying the system parameters (X_i's) in Equation 1, one must also determine the appropriate human behavior (Y). The embedded performance assessment discussed by Williges (1977) potentially involves a variety of measures dealing with time to complete a task, operator waiting times, error rates, etc. which can be automatically recorded by the computer system while the operator is using the interactive terminal. But, embedded performance measures are only one class of metrics that can be used to evaluate the overall human/computer interface. Other classes of metrics include the human operator's subjective ratings of satisfaction with the system configuration and work sampling measures estimating the proportion of time spent in various aspects of the interactive human/computer task. Each of these two metrics classes have been used only to a limited extent in evaluating operator behavior in interactive systems (See, for example, Miller, 1977; and Hoecker and Pew, 1979).

Objective

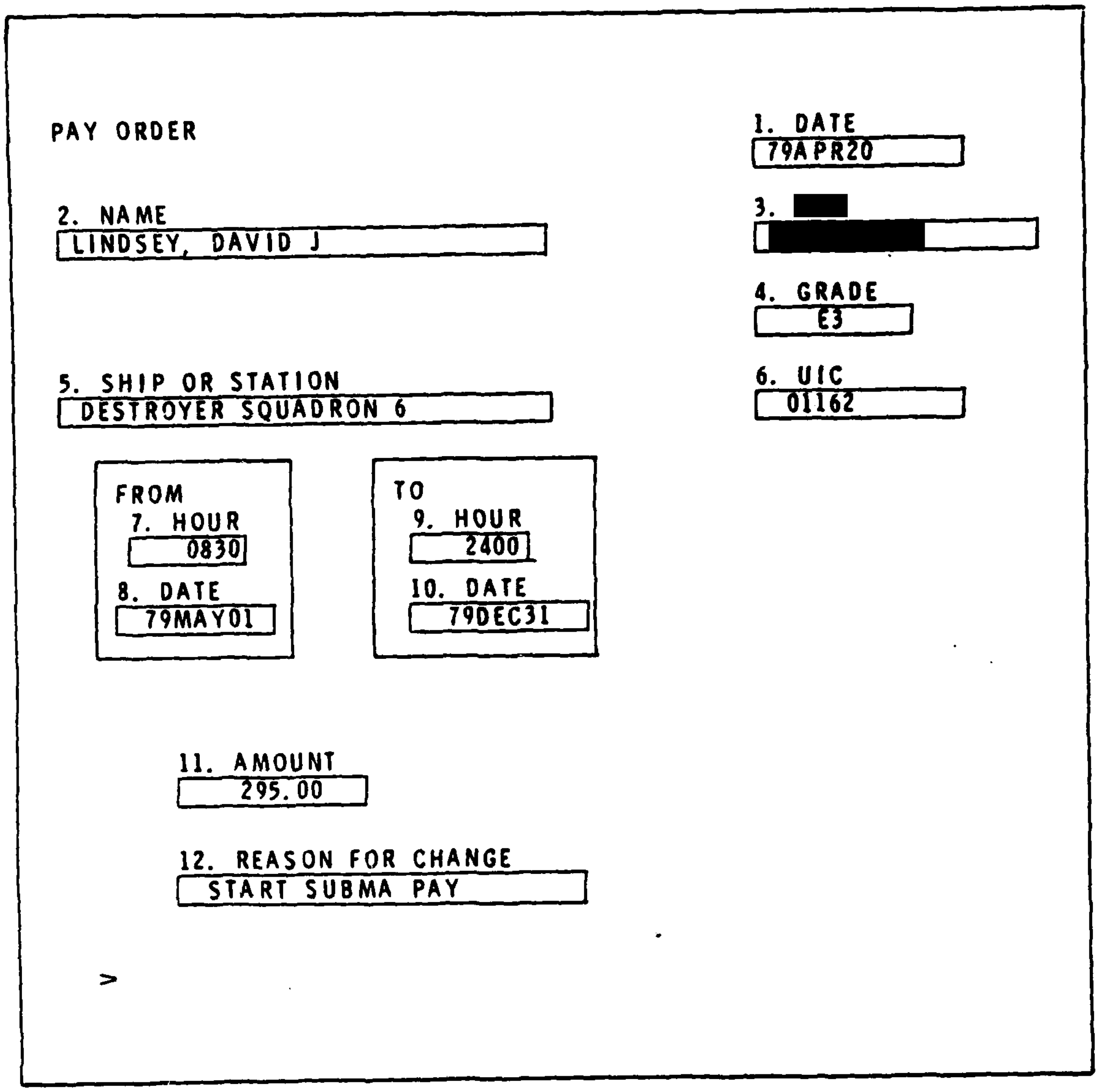
The purpose of this study is to demonstrate the utility of incorporating all three classes of metrics in evaluating human/computer interactions. Each class of measures was used separately in generating functional relationships between human behavior and four systems parameters; the resulting functional relationships were integrated in a multivariate analysis to provide an overall description of the human/computer interface.

METHOD

Experimental Task

Personnel Records Task

The general task environment was structured around a Navy personnel records task in which the operator was required to use an interactive computer terminal to perform specified transactions on simulated personnel records. The particular transaction used in this study was a form-filling task analogous to a pay order form used to issue a temporary pay change for a given individual. Figure 1 depicts the display layout of the pay order form as used in this study. Alphanumeric information was entered into a series of twelve fields designated on the display as shown in Figure 1. The cursor symbol (>) shown at the bottom of Figure 1 designated a working area of the display used for query language commands. When data were entered in any field, the cursor was first moved to that field to activate the area. These fields included information items such as date, name, social security number, duty station, amount of pay, reason for change, etc. Specific Navy format rules were followed for entering the date, name, and times in the appropriate fields on the interactive terminal. Even though all records used in this experiment were simulated, they did represent the type of information and formatting rules used in actual Navy personnel records.



PAY ORDER

1. DATE
79APR20

2. NAME
LINDSEY, DAVID J

3. [redacted]
[redacted]

4. GRADE
E3

5. SHIP OR STATION
DESTROYER SQUADRON 6

6. UIC
01162

FROM
7. HOUR
0830
8. DATE
79MAY01

TO
9. HOUR
2400
10. DATE
79DEC31

11. AMOUNT
295.00

12. REASON FOR CHANGE
START SUBMA PAY

>

Figure 1. Display format used in the personnel records data entry task.

Each subject was required to perform either ADD or CHANGE transactions on these records. The ADD command was used to add new records to the system, whereas the CHANGE command was used to modify existing personnel records. All information pertaining to the revision and addition to records was presented on an adjacent plasma panel via a PLATO IV terminal (Bitzer and Johnson, 1971) connected to the University of Illinois PLATO system. The presentation of these ADD and CHANGE requests was either structured according to the format used on the form-filling interactive display or unstructured in a free flowing text format.

The arrangement of the terminal work area closely followed the procedures reported by Beatty and Williges (1980). Figure 2 shows this arrangement which consisted of two side-by-side plasma panels. The plasma panel on the right side was the PLATO IV terminal used for instructions as well as the ADD and CHANGE requests during data entry in the actual experimental trials. The left-hand terminal was a special purpose plasma panel developed by Information Technology Limited (ITL) which was used for data entry in the experiment. This display projected the pay order form shown in Figure 1 and was used interactively by the subjects in the form-filling task. A one-way communication channel existed between the ITL plasma panel and the PLATO IV terminal which called the next data entry request to be performed at the completion of the preceding request.

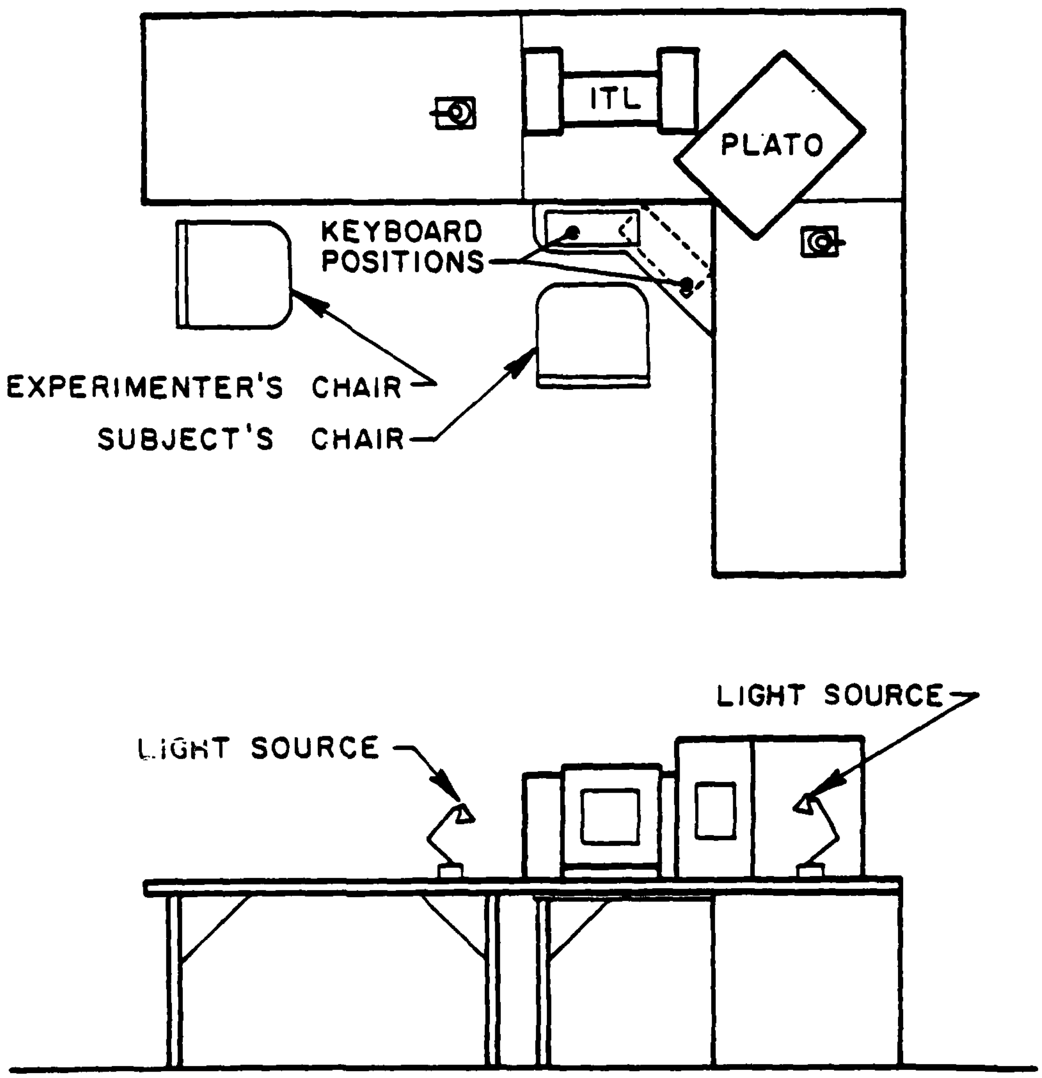


Figure 2. Arrangement of the interactive computer terminals used in the data entry task.

Generic Task Simulation

To facilitate the experimental evaluation of automated performance assessment in a personnel records task, a generic, single-operator, event-based task simulation was developed. The hardware for this system is a 512 x 512 parallel-plasma panel interfaced directly to a laboratory PDP 11/5˜ minicomputer. The parallel display panel is equipped with both a 32 x 32 touch panel entry and a keyboard input capability to the PDP 11/55 computer. The computer stores the simulated personnel records for the performance assessment task, interprets queries made by the subject during personnel records transactions, and records the subject's task performance in terms of errors and response latencies. These performance measures, in turn, are used as the dependent measures in the performance assessment profiles.

Two general software routines were programmed in connection with the generic task simulation. One routine allows for general purpose communication between the PDP 11/55 computer and the parallel-plasma panel. This set of assembly language routines enables one to write a variety of alphanumeric characters on the panel as well as perform various line drawing operations. The second set of software programs was developed to generate the generic, event-based task. These programs produce a table driven task simulation which allows for such things as: record additions/deletions, record switching, page switching, field switching, updating, and a primitive command language. Details on the design of this generic task simulation as well as a complete source list of the various subroutines are provided by Mason, Evans, and Beatty (1979).

Subjects

Four undergraduate students at Virginia Polytechnic Institute and State University were used as subjects in this experiment. The three male and one female subjects received $3.00/hour for their participation. Each subject had no previous experience in making personnel transactions on a computer-based system.

Independent Variables

Four parameters relating to various timing parameters of the computer system were manipulated. These variables included system delay (SD), display rate (DR), echo rate (ER), and buffer length (BL). Levels of each of these independent variables were set according to results of pretest data, effective ranges noted in the scientific literature, and realistic ranges encountered in interactive system operation.

The SD variable controlled the delay time (in seconds) between an operator's input command (e.g., search files, next field, etc.) and the computer executions of that command signified by returning control to the operator. The DR variable manipulated the rate (in characters/second) at which characters were displayed on the screen and was somewhat analogous to baud rate characteristics of standard terminals. The last two factors were both related to keyboard entry timing. ER represented the delay time (in seconds) between a keystroke and the appearance of that character on the display screen. BL referred to the number of characters typed on the keyboard that could be held in a buffer memory awaiting display on the interactive plasma panel.

Experimental Design

To provide the necessary and sufficient data to solve the polynomial expression stated in Equation 1 in an economial fashion, a four-factor central-composite design was used. An orthogonal version of this design was chosen with equal replication across the entire design yielding the 25 unique treatment combinations of five levels of each of the four independent variables shown in Table 1. (See Williges, 1980, for a detailed description of the development and use of central-composite designs in behavioral research.) The linear transformation between the coded values of the central-composite design and the real-world values of the four systems variables are summarized in Table 2.

Each subject received four trials on each of the resulting 25 treatment combinations thereby yielding a within-subject design. The four trials consisted of a one-half fractional replicate of the combination of prompting tone (on or off), trial presentation (structured or unstructured information), and task type (adding a record or changing an existing record). The third-order interaction was used as the defining contrast in choosing the one-half replicate such that two subjects received one of the resulting replicates and the other two subjects received the other replicate.

Procedures

Each subject received a computer-assisted instruction lesson on the PLATO terminal before participating in the experiment.

Table 1
Coded Values of Unique Treatment Combinations:
A Four Factor Central Composite Design

Treatment Condition	System Delay	Display Rate	Echo Rate	Buffer Length
	Independent Variables			
1	+1	+1	+1	+1
2	+1	+1	+1	-1
3	+1	+1	-1	+1
4	+1	+1	-1	-1
5	+1	-1	+1	+1
6	+1	-1	+1	-1
7	+1	-1	-1	+1
8	+1	-1	-1	-1
9	-1	+1	+1	+1
10	-1	+1	+1	-1
11	-1	+1	-1	+1
12	-1	+1	-1	-1
13	-1	-1	+1	+1
14	-1	-1	+1	-1
15	-1	-1	-1	+1
16	-1	-1	-1	-1
17	+1.414	0	0	0
18	-1.414	0	0	0
19	0	+1.414	0	0
20	0	-1.414	0	0
21	0	0	+1.414	0
22	0	0	-1.414	0
23	0	0	0	+1.414
24	0	0	0	-1.414
25	0	0	0	0

Table 2
Linear Transformations Between Coded Values
Used in the Central-Composite Design and Real
World Levels of the Four System Variables

	Levels of the Four Independent Variables				
	-1.414	-1	0	+1	+1.414
System Delay (SD)	0.10	1.55	5.05	8.55	10.00
Display Rate (DR)	240	206	125	44	10
Echo Rate (ER)	0.00	0.22	0.75	1.28	1.50
Buffer Length (BL)	1	2	4	6	7

This lesson lasted approximately 45 minutes and provided general instruction on the interactive display used in the experimental sessions as well as the rules for listing names, dates, and times.

Following the practice session, each subject participated in five experimental sessions each consisting of four trials on five treatment combinations. The five treatment combinations were chosen randomly for each subject. Consequently, each subject was required to complete 100 personnel records throughout the course of the experiment. In addition, each subject received four practice trials in the first experimental session to become familiar with the experimental protocal. These four practice trials included the +1.414 levels of all factors on two trials and the -1.414 levels of all factors on the other two trials, thereby showing each subject the possible range of treatment conditions.

Dependent Variables

Three general classes of dependent variables were measured in this study. These classes included work sampling, embedded performance assessment, and operator satisfaction ratings. As shown in Table 3, several specific measures were collected within each of these general categories to provide a total of 22 dependent variables.

Table 3
Classes of Dependent Variables Used in the Principal Components Analysis

---

Work Sampling

- Looking at Information (INF)
- Looking at Display (DSP)
- Looking at Keyboard (KBD)
- Information/Typing (INF/TYP)
- Display/Typing (DSP/TYP)
- Keyboard/Typing (KBD/TYP)

Embedded Performance Assessment

- Typing Rate (TRATE)
- Field Entry/User Response Time (FE/URT)
- Next Field/User Response Time (NF/URT)
- Field Entry/Ready Time (FE/RT)
- Next Field/Ready Time (NF/RT)
- Ready Responses (RDRSP)
- Character Erasures (CHER)
- Checking Time (CKT)

Satisfaction Ratings

- Tone Rating (TONR)
- System Delay Rating (SDR)
- Display Rate Rating (DSPR)
- Echo Rate Rating (ERR)
- Buffer Length Rating (BLR)
- Speed Rating (SPEED)
- Accuracy Rating (ACCUR)
- Overall Rating (OVER)

Work Sampling

Thoughout the entire experimental session a closed-circuit television system was used to monitor the time spent by each subject on various aspects of the personnel transcription task. The overall task was divided into six mutually exclusive components. Three of these components dealt with viewing information on either the PLATO terminal (INF), the interactive plasma panel display used in the data entry task (DSP) or the data entry keyboard (KBD). The other three components were concerned with typing (data entries while viewing either the input information (INF/TYP), the interactive display (DSP/TYP), or the keyboard (KBD/TYP). Random observations were made throughout the experimental session to obtain estimates of he portion of task time devoted to each of these six categories. The mean duration between samples was 5 seconds, and the possible durations randomly sampled was 3, 4, 5, 6, and 7 seconds, respectively.

Embedded Performance Measures

The generic task simulation allowed for on-line data collection of several aspects of operator performance while using the interactive terminal. Specifically, the metering included a complete transcription of keystroke inputs, command type, and a variety of performance measures. User times were separated into response time, which referred to the elapsed time from a computer prompt to a keystroke input, and ready time, which is the time a user is ready to make an input but the computer is unable to respond. The eight embedded performance measures used in this study included the operator's typing rate (TRATE), the user's response time for making a field entry (FE/URT) or for selecting the next field (NF/URT), the user's ready time before a field entry (FE/RT) or next field (NF/RT), the number of ready responses (RDRSP) the number of character erasures (CHER), and the checking time (CKT) needed to ascertain that the correct record was chosen from the database.

Satisfaction Ratings

The two practice trials during the first experimental session served as a means of anchoring the subject's satisfaction rating. Following each set of four trials on a particular treatment combination, each subject was required to complete a 10 point, Likert-type rating scale evaluating the prompting tone (TONR), each of the four independent variables (SDR, DSPR, ERR, BLR), and operator satisfaction of the systems variables on speed (SPEED), accuracy (ACCUR), and overall performance (OVER). The complete list of questions used in the rating scale is provided in Appendix A.

RESULTS AND DISCUSSION

Both univariate and multivariate analyses were conducted on the 22 dependent variables shown in Table 3. The results of each set of these analyses are presented separately.

Univariate Analyses

Before evaluating the various effects of the system timing variables manipulated in this study, a preliminary analysis was conducted on the fractional replication of the three control variables used to construct the data entry task, i.e., the alerting tone, the structuring of the information, and the entry task type. Essentially, there were no significant differences ($p > .05$) between ADD or CHANGE tasks and the interactions of these control variables with the system timing variables. Overall, however, the presence of the tone and the structuring of the information presented to the subjects had significant effects ($p < .01$) on the percent of time spent viewing the display as well as user response times during data entry. Specifically, the alerting tone increased the amount of time spent viewing the information display and decreased both next field and field entry user response time. And, as expected, the unstructured trials caused subjects to spend more time viewing the information and increased the field entry user response times. Since the control variables only had these overall effects, the trials were combined for the subsequent univariate and multivariate analyses.

The overall analysis pertains to the three metrics of satisfaction ratings, work sampling, and embedded performance measures. In each dependent variable category, second-order polynomial regression equations were calculated to determine the functional relationship between a specific dependent variable and the four system timing variables manipulated in this experiment. Standard least square regression procedures were used to fit these polynomial expressions. Subsequently, an analysis of variance was conducted on each regression analysis to isolate the statistically significant predictors. Comparisons among the different metrics, therefore, can be made directly in terms of the differential characteristics of the various polynomial regression equations. In addition, a second-order, orthogonal design was used so that the partial regression weights based on coded data would be uncorrelated thereby facilitating the interpretation of these relative comparisons.

A complete summary of each of the separate polynomial regression equations as well as the subsequent analysis of variance are presented in Appendix B. A listing of the significant predictors of each of these polynomial regressions is presented in Table 4 for easy reference. The interpretation and discussion of each of these analyses is presented separately by class of metric.

Work Sampling

System timing variables affect the amount of time devoted to various aspects of the task. Overall, Figure 3 shows that

Table 4
Summary of Polynomial Regression Analysis
of Variance for Separate Dependent Variables

Metric	R^2	Significant Predictors ($p<.01$)
		Work Sampling
INF	.044	-
DSP	.362	ER, SD, DR^2, ERxSD
KBD	.076	SD^2
INF/TYP	.081	SD
DSP/TYP	.091	ER
KBD/TYP	.341	ER, SD, ERxSD
		Embedded Performance Assessment
TRATE	.613	BL, ER, ER^2, BLxER, ERxDR
FE/URT	.253	SD, SD^2
NF/URT	.082	SD
FE/RT	.456	SD, SD^2
NF/RT	.418	SD, SD^2
RDRSP	.357	SD
CHER	.063	ER
CKT	.067	DR
		Satisfaction Ratings
TONR	.115	ER
SDR	.530	ER, SD, SD^2, ERxDR
DSPR	.141	DR. SD, BL^2, ER^2, BLxDR
ERR	.510	ER, SD, ER^2, SD^2
BLR	.455	ER, SD, BL^2, ER^2, SD^2, BLxER
SPEED	.586	ER, SD, ER^2, SD^2, ERxSD
ACCUR	.464	ER, SD, ER^2, SD^2, ERxSD
OVER	.519	ER, DR, SD, ER^2, SD^2, ERxDR, ERxSD

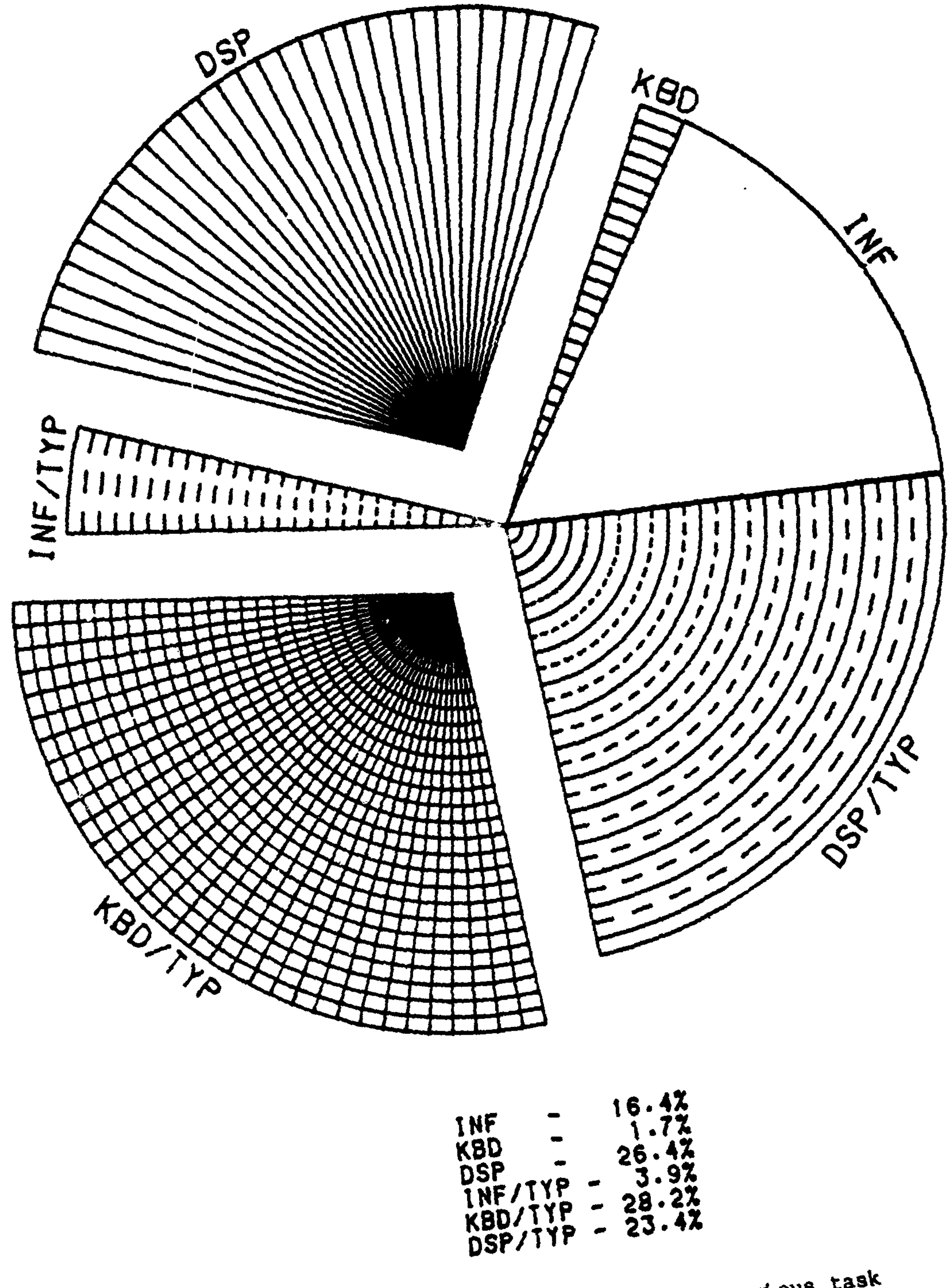


Figure 3. Proportion of time devoted to various task components in the work sampling analysis.

operators spent significantly different ($p<.01$) amounts of time in various aspects of the personnel transaction task. The two largest proportions of time were spent in viewing the interactive display (DSP), and viewing the keyboard while entering data (KBD/TYP). These proportions were .26 and .28, respectively, of the total time.

Subsequent polynomial regressions of the time spent in various aspects of the task as a function of system timing variables showed high multiple correlations for both DSP and KBD/TYP (i.e., $R^2=.36$ and $R^2=.34$, respectively). In both polynomial regressions the SD and ER variables were the primary predictors of work sampling time as shown in Table 4, but the effects of these two variables were quite dissimiliar. To aid in interpreting these differential effects, the complete second-order polynomial function as well as a transect plot of DSP and KBD/TYP performance as a function of the two significant factors SD and ER are shown in Figures 4 and 5, respectively. The other two system variables are held constant at the 0 coding level. (Note that the plots represent second-order functions and the minor perturbations shown in the figures are merely artifacts of the particular nearest neighbor algorithm used for creating the plots and the location of predicted data points across the surface.)

Figure 4 shows that the operator is spending increasingly more time viewing the interactive display as SD and ER increase. This additional viewing time is necessary both to cross-check echoing of a typed character and to look for the computer prompt

LOOKING AT DISPLAY (DSP)

$$\begin{aligned} DSP = {} & 0.2371 + 0.0017BL + 0.0261ER + 0.0028DR \\ & + 0.0831SD - 0.0005BL^2 + 0.0015ER^2 + 0.0288DR^2 \\ & + 0.0039SD^2 + 0.0101BL*ER - 0.0135BL*DR \\ & - 0.0025BL*SD + 0.0041ER*DR - 0.0210ER*SD \\ & - 0.0054DR*SD \end{aligned}$$

$$R^2 = .361$$

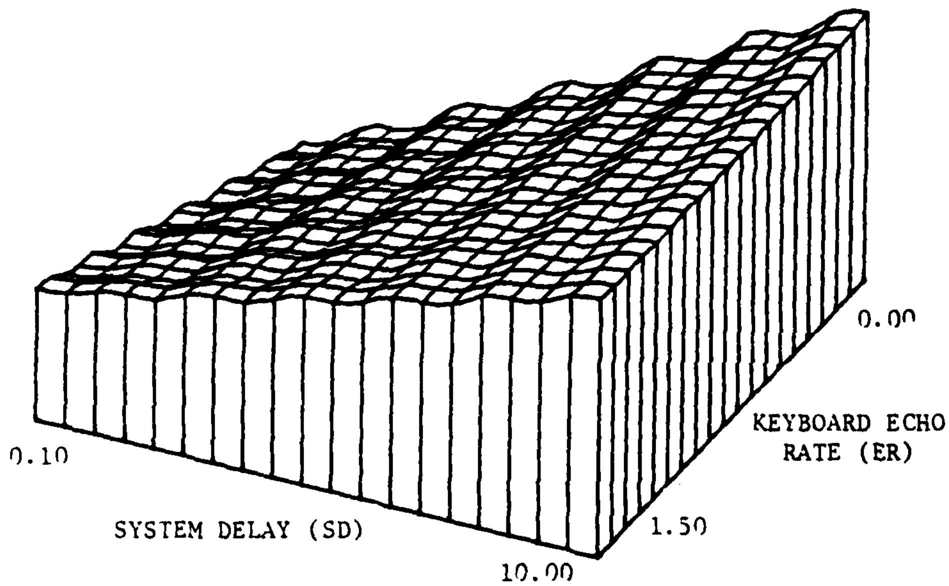


Figure 4. Response surface for looking at display as affected by echo rate and system delay.

KEYBOARD/TYPING (KBD/TYP)

$$
\begin{aligned}
KBD/TYP = {} & 0.2751 + 0.0057BL - 0.0558ER + 0.0019DR \\
& - 0.0768SD - 0.0020BL^2 + 0.0114ER^2 + 0.0123DR^2 \\
& - 0.0134SD^2 - 0.0121BL*ER - 0.0001BL*DR \\
& + 0.0153BL*SD - 0.0069ER*DR + 0.0233ER*SD \\
& + 0.0045DR*SD
\end{aligned}
$$

$$R^2 = .341$$

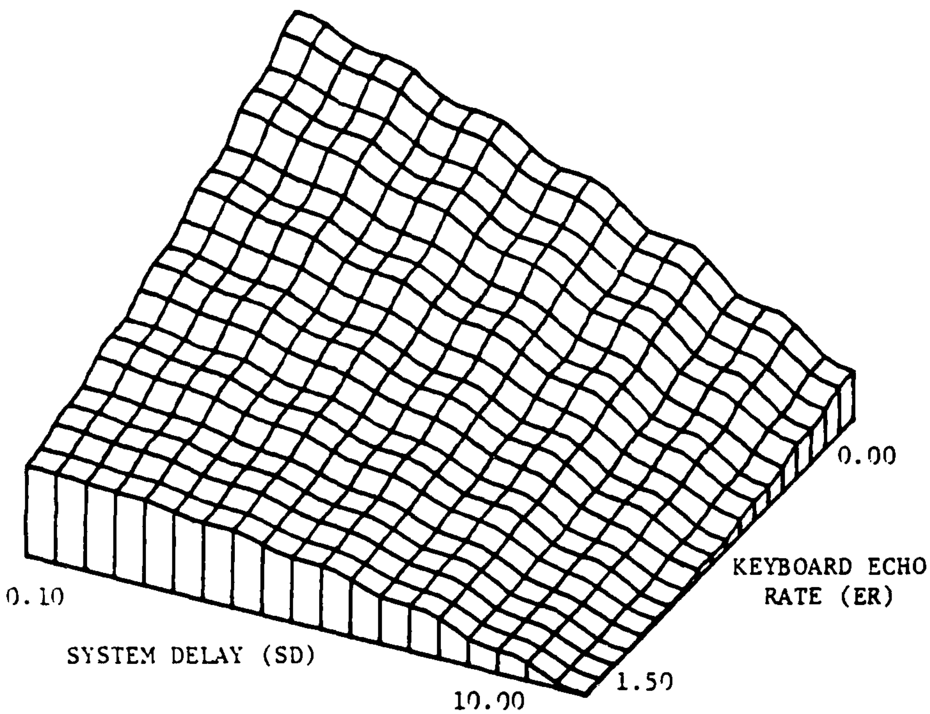


Figure 5. Response surface for keyboard/typing as affected by echo rate and system delay.

signifying computer availability for the next command input. Results from the KBD/TYP prediction equation, as depicted in Figure 5, show opposite effects. Namely, the operator spends more time viewing the keyboard and typing when SD and ER are short, thereby allowing more immediate access to the computer. Additionally, Figure 5 shows that the proportion of time spent on KBD/TYP decreases rapidly in a non-linear fashion as SD and ER increase.

<u>Embedded Performance Assessment</u>

The summary of the eight measures of operator performance measures provided in Table 4 show that all the system timing variables had a significant ($p<.01$) effect on operator performance with at least one dependent variable. The dependent variable with the highest multiple correlation in the regression analysis was TRATE rate ($R^2=.61$). Two other regression analyses dealing with operator ready times (FE/RT and NF/RT) also yielded high multiple correlations ($R^2=.46$ and .42, respectively. In the user ready time analyses, the SD independent variable was the primary predictor showing that operator ready time increased as system delay time increased.

The typing rate analysis, however, resulted in no significant ($p<.05$) effect due to SD. Alternatively, BL rather than SD combined with ER as the primary significant predictors ($p<.01$). The resulting perspective response surface of BL and ER effects on operator typing rate is shown in Figure 6. Typing rates are quite low when only one character is held in the

TYPING RATE (TRATE)

$$\begin{aligned}\mathrm{TRATE} = {} & 0.020 + 0.000BL - 0.007ER + 0.000DR \\ & - 0.000SD - 0.000BL^2 + 0.001ER^2 - 0.000DR^2 \\ & + 0.000SD^2 + 0.001BL*ER - 0.000BL*DR \\ & - 0.000BL*SD - 0.001ER*DR - 0.000ER*SD \\ & - 0.000DR*SD\end{aligned}$$

$$R^2 = .613$$

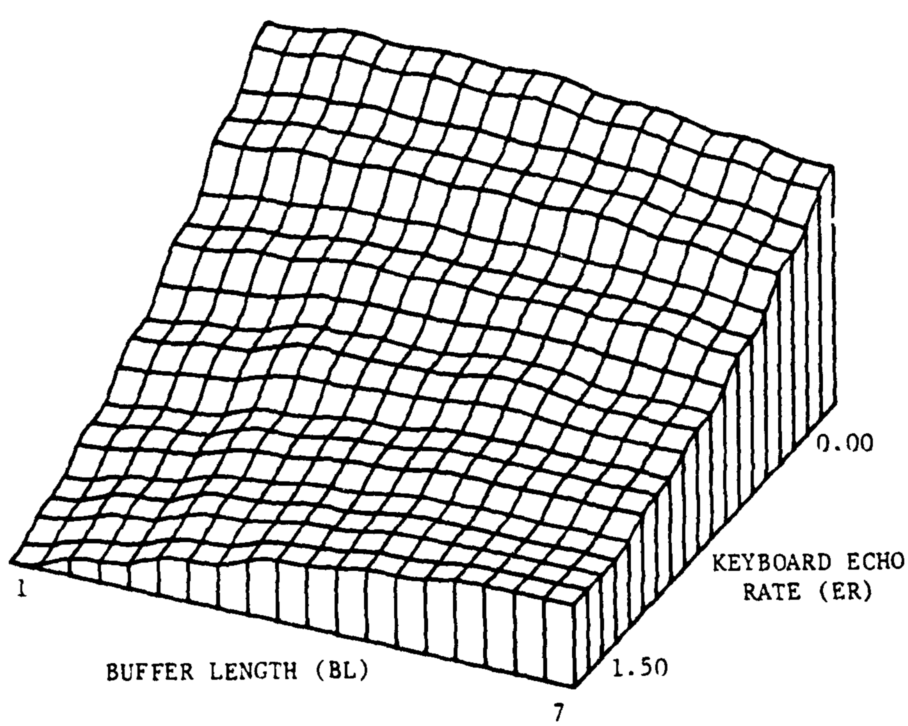


Figure 6. Response surface for typing rate as affected by echo rate and system delay.

keyboard buffer and echo rates of typed characters are delayed by 1.50 seconds. In this situation the operator can quickly overtype the keyboard buffer due to the long echo delays with the result that the character is never entered into the computer. It appears that this particular combination of system variables forces operators to slow their input rates to match the slower computer system characteristics. The results shown in Figure 6 also suggest that the short buffer length can be compensated for easily by short echo delays, but a larger buffer length does not compensate for long echo delays to any great extent.

Satisfaction Ratings

The third category of metrics summarized in Table 4 deal with various measures of operator satisfaction. Ratings of satisfaction with the separate timing variables reflected significant predictors of each of those factors in the polynomial regression. The more important rating scales, however, dealt with SPEED, ACCUR, and OVER. Surprisingly, these three ratings were highly correlated and resulted in essentially the same functional relationship relating the systems variables. Namely, the significant ($p<.01$) partial regression weights include both first- and second-order effects of system delay and keyboard echo rate (i.e., SD, ER, SD^2, ER^2, and SD*ER).

To summarize this effect, the polynomial regression and transect plot of the operator's overall rating of satisfaction as a function of the two significant factors SD and ER are shown in Figure 7. The other two system variables are held constant at the 0 coding level. Clearly, the subjects were satisfied (high rating) with the fastest SD and ER, but their satisfaction decreased rapidly as timing delays were introduced. In fact, Figure 7 shows a flat plateau of almost total dissatisfaction when SD was greater than 5 seconds and ER was more than 0.75 seconds delayed.

Multivariate Analyses

Rather than consider each of the dependent variables separately, one can consider combinations of these measures which define necessary and sufficient metric classes needed to describe human/computer interactions. For example, the three general metrics used in the univariate analyses are quite distinct as measurement categories, but may not be totally distinct in terms of behavioral dimensions. Subsequent multivariate analyses were conducted in an attempt to isolate these underlying behavioral dimensions. First, a principal component analysis was conducted to cluster the metrics. The resulting dimension score from the principal components analysis was then used as the dependent variable in a subsequent polynomial regression analysis to evaluate the functional relationship between the system timing variables and the behavioral dimensions.

Principal Components Analysis

To estimate the underlying behavioral dimensions a principal components analysis was conducted on twenty-one of the dependent variables shown in Table 3. To avoid the problem of colinearity

OVERALL RATING (OVER)

$$
\begin{aligned}
OVER = {} & 2.390 + 0.190BL - 1.774ER - 0.305DR \\
& - 0.917SD + 0.005BL^2 + 1.068ER^2 + 0.256DR^2 \\
& + 0.881SD^2 + 0.109BL{*}ER - 0.109BL{*}DR \\
& - 0.029BL{*}SD + 0.328ER{*}DR + 0.640ER{*}SD \\
& + 0.046DR{*}SD
\end{aligned}
$$

$$R^2 = .519$$

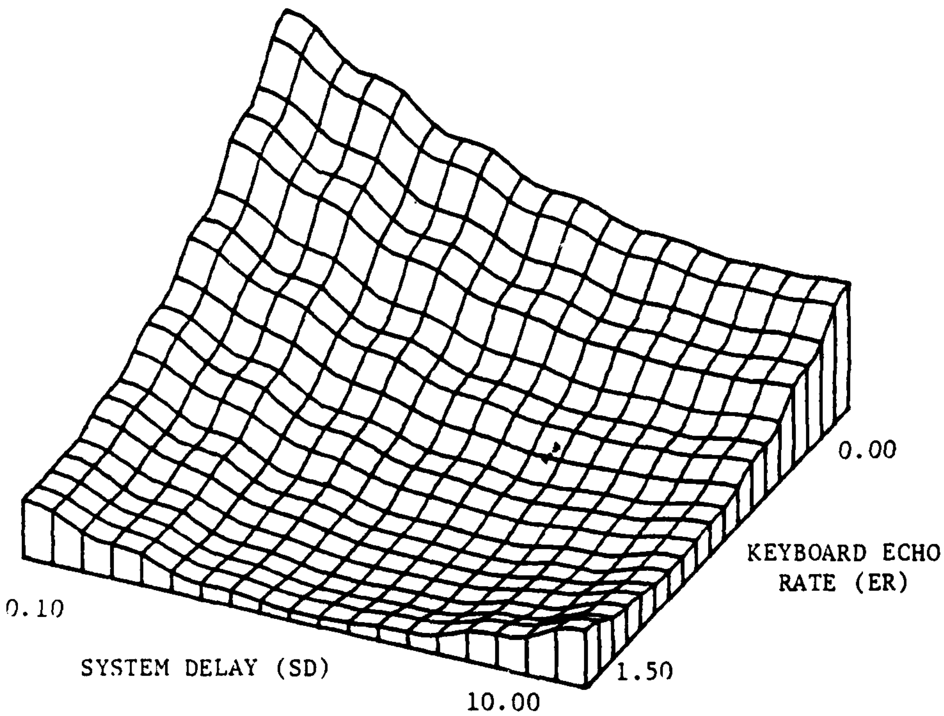


Figure 7. Response surface for overall rating as affected by echo rate and system delay.

in the work sampling data, the KBD dependent variable which represented the smallest percent of time was eliminated. The dependent variables used were drawn from the major independent variables in each of the three metric classes of work sampling, embedded performance assessment, and satisfaction ratings. The dependent measures were recorded across the four subjects on each of the four trials of the resulting twenty-five treatment combinations shown in Table 1, thereby resulting in a 21 x 400 matrix for the principal components analysis.

The results of the principal components analysis are summarized in Table 5 which shows the orthogonally rotated dimension loadings for each of the twenty-one dependent measures across the three principal components. These three components together account for 51.1% of the variance. If additional dimensions are added beyond these three, the percent contribution drops markedly. Consequently, the three dimensions shown in Table 4 seem to describe the clustering most parsimoniously. These three clusters seem to represent human/computer interface dimensions of operator production, waiting, and planning activities.

By using the orthogonally rotated weighting matrix, interpretation of the principal components analysis is facilitated. As shown in Table 4, the first dimension, which accounts for 28.5% of the variance, is most heavily weighted on typing rate and ratings of echo rate, buffer length, speed, accuracy, and overall satisfaction. In other words this dimension appears to be related to PRODUCTION activities of the operator.

Table 5
Orthogonally Rotated Factor Pattern of the Principal Components Analysis

METRIC	1 PRODUCTION	2 WAITING	3 PLANNING
INF	-0.028	0.271	0.371
DSP	-0.071	-0.577	-0.119
INF/TYP	0.098	0.195	0.092
DSP/TYP	-0.165	-0.127	-0.549
KBD/TYP	0.292	0.399	0.337
TRATE	0.744	-0.143	0.288
FE/URT	0.112	0.273	-0.599
NF/URT	0.087	0.096	-0.663
FE/RT	-0.117	-0.870	0.119
NF/RT	-0.069	-0.878	0.169
RDRSP	-0.033	-0.751	0.147
CHER	-0.261	0.132	0.071
CKT	0.038	0.055	-0.233
SDR	0.359	0.738	-0.092
TONR	0.195	0.008	0.759
DSPR	0.053	0.311	0.382
ERR	0.850	0.151	0.028
BLR	0.734	0.194	0.058
SPEED	0.863	0.328	-0.062
ACCUR	0.860	0.352	-0.010
OVER	0.876	0.354	-0.002
EIGENVALUES	5.983	2.798	1.951
% TOTAL VARIANCE	28.5%	13.3%	9.3%

The second dimension accounts for 13.3% of the variance and appears to be representative of the operator's WAITING activities. Metrics such as time spent viewing the display, field entry and next field ready times, operator ready responses, and ratings of system delay weigh most heavily on the operator's waiting dimension.

Although the third dimension accounts for only 9.3% of the variance, it does appear to represent another feature of the human/computer interface which is separate from the first two. Dependent variables including time spent viewing the display while typing, next field and field entry user response times, and ratings of the cueing tone were the primary measures clustered on this dimension which appears to be related to PLANNING activities. Since the personnel records tasks used in this study was primarily a transcription task, one would expect planning activities to account for only a small portion of the operator's performance. In other human/computer tasks, this activity may become much more important.

Multivariate Response Surfaces

Each of the three composite human/computer interface dimensions (i.e., PRODUCTION, WAITING, and PLANNING) were used separately to determine the functional relationships among the system timing variables. A weighted dimension score was determined for each unrotated dimension and was used as the dependent variable in the polynomial regression analysis. A complete second-order polynomial regression was calculated to predict production, waiting, and planning activities as a function of the four system timing variables. The results of these analyses are summarized in Appendix C.

Even though each of the three regressions had significant predictors, the prediction equations for both PRODUCTION and WAITING activities accounted for substantially more variance (R^2 of .523 and .517, respectively) than the prediction of PLANNING activities ($R^2 = .162$). Although comparisons are presented among all three dimensions for completeness, the low multiple correlation coefficient for PLANNING makes interpretation of this dimension somewhat suspect.

Linear and quadratic effects of system response time and keyboard echo rates were the primary predictors of PRODUCTION and PLANNING activities ($p<.001$); whereas, the linear effects of all four timing variables and the quadratic effect of keyboard echo rates were the main significant predictors of WAITING activities ($p<.05$). To illustrate the differential effects of the system timing variables, perspective response surfaces of operator production, waiting, and planning activities are shown in Figures 3, 4, and 5 respectively, with buffer length and display rate held constant at the mean levels.

By comparing Figures 8, 9, and 10, one can see that system delay and keyboard echo rate were important predictors of operator activities, but these variables affected operator behavior differentially. Figure 8 shows production activity to be highest at the shortest system delay and keyboard echo rate. As delays in either of these two system timing variables

PRODUCTION (P)

$$P = -0.43 + 0.07BL - 0.57ER - 0.05DR - 0.62SD - 0.02BL^2 + 0.30ER^2 + 0.07DR^2 + 0.19SD^2 + 0.06BL*ER - 0.06BL*DR - 0.07BL*SD + 0.05ER*DR + 0.13ER*SD - 0.02DR*SD$$

$$R^2 = .623$$

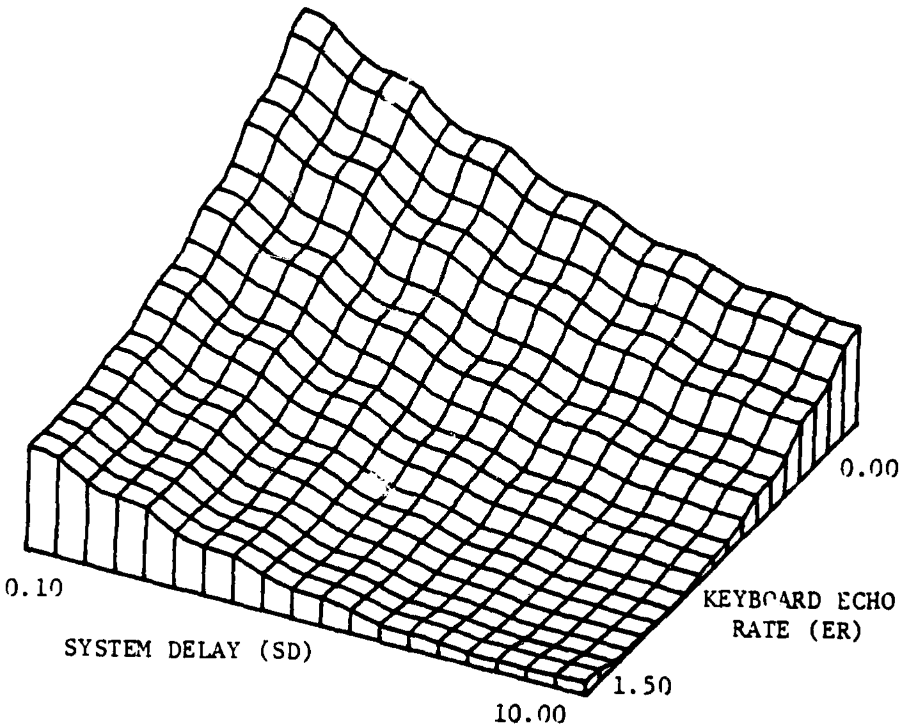


Figure 8. Response surface for production as affected by echo rate and system delay.

WAITING (W)

$$W = -0.15 + 0.13BL - 0.54ER + 0.08DR + 0.55SD - 0.08BL^2 + 0.13ER^2 + 0.06DR^2 + 0.07SD^2 + 0.04BL*ER - 0.09BL*DR - 0.06BL*SD - 0.07ER*DR + 0.02ER*SD - 0.04DR*SD$$

$$R^2 = .517$$

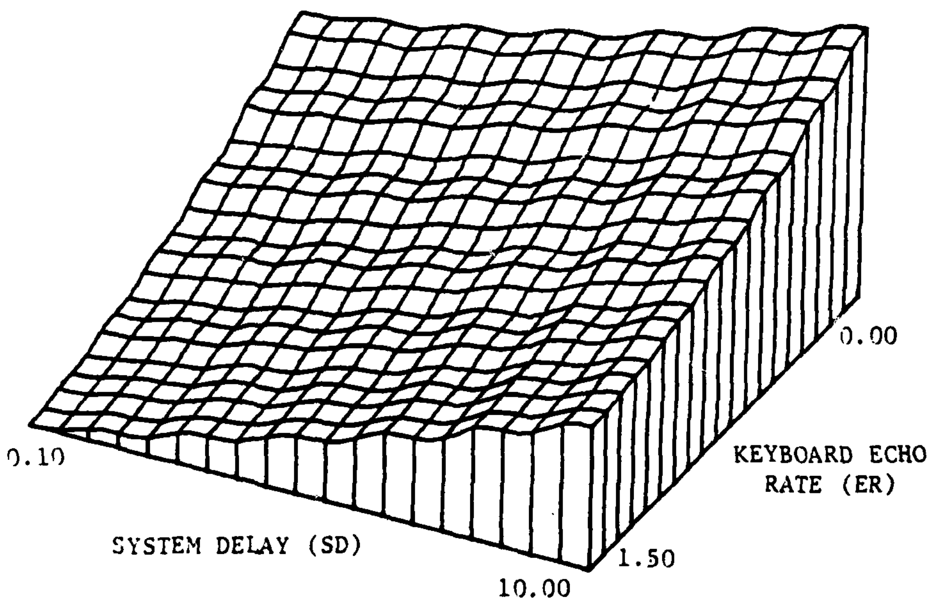


Figure 9. Response surface for waiting as affected by echo rate and system delay.

PLANNING (PL)

$$PL = -0.43 + 0.03BL - 0.23ER - 0.07DR + 0.26SD + 0.04BL^2 + 0.10ER^2 + 0.03DR^2 + 0.36SD^2 + 0.01BL*ER + 0.01BL*DR + 0.05BL*SD + 0.05ER*DR - 0.03ER*SD + 0.11DR*SD$$

$$R^2 = .163$$

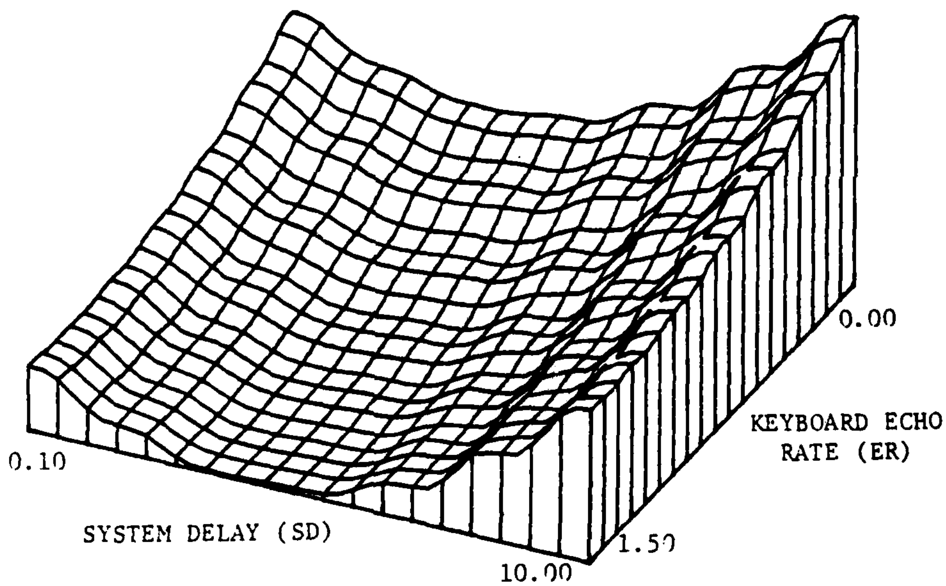


Figure 10. Response surface for planning as affected by echo rate and system delay.

increase, production activity decreases markedly. On the other hand, waiting activities as shown in Figure 9 are lowest when the system delay is shortest and keyboard echo rate is the longest. In this case, the long keyboard echoing rates mask the system response time effects because the operators cannot make ready responses quickly. Other differences are due to the significant buffer length and display rate effects which increase WAITING activities. Finally, Figure 10 shows a marked curvilinear effect of system delay such that PLANNING activities are reduced at an intermediate system delay and increase at extremely slow and fast system delays.

Composite Multivariate Surface

Tradeoffs among the three multivariate surfaces can be made by superimposing the surfaces to form a composite multivariate surface. These composite surfaces can be constructed in a variety of ways depending upon the weightings chosen for the separate surfaces. Two of these alternatives are shown in Figure 11 which depicts the composite of PRODUCTION activities added to the inverse of WAITING and PLANNING activities. These composite surfaces then represent combined throughput where the high score equals high PRODUCTION and low WAITING and PLANNING activities.

Figure 11a depicts the composite surface based on equal and additive contributions of the three separate activities; whereas, Figure 11b depicts a composite surface based on differential contributions of the three separate activities. Specifically, the differential contributions in Figure 11b are determined by

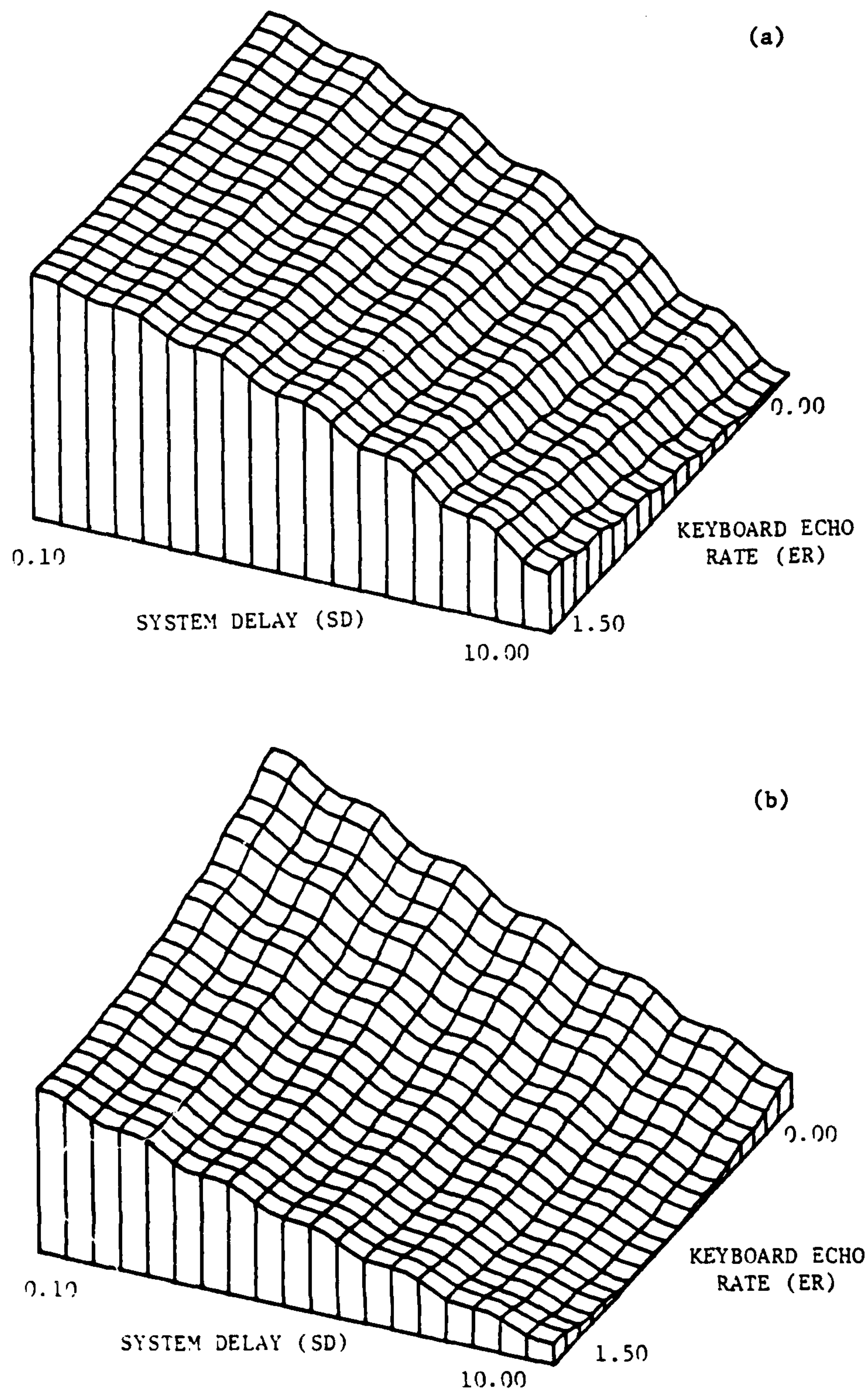


Figure 11. Composite response surfaces of three multivariate dimensions using (a) additive contributions and (b) percent of variance accounted for by each dimension.

the percent of variance accounted for by the PRODUCTION, WAITING, and PLANNING dimensions (i.e., 28.5%, 13.3%, and 9.3%, respectively). By comparing Figures 11a and 11b, one can see that these two strategies result in slightly different composite surfaces. When the three activities are combined in an additive manner (Figure 11a), the composite surface is almost a rising plain that is dominated by SD. On the other hand, when the composite surface is based on percent of variance (Figure 11b), it then appears more characteristic of the PRODUCTION activity surface which is weighted most heavily in the composite. Clearly, one must give careful consideration to the weighting alternatives in order to generate the composite surface most appropriate for a particular system applications.

CONCLUSIONS

Clearly, all three classes of metrics are needed to provide a complete analysis of the effects of the four systems variables on operator behavior. By choosing any of these metric classes only part of the description of operator behavior is available. Not only do different metric classes show different functional relationships for the same system variables, but they also show that different system variables are primary determiners of operator behavior in different metric classes. By using these three classes of measures and representing the functional relationships in terms of response surfaces, the system designer can easily superimpose the various surfaces to make the necessary human/computer interface design tradeoffs.

Besides using the separate dependent measures to determine specific system design considerations, the multivariate response surfaces allows for a more general interpretation of the human/computer interface. These multivariate analyses represent operator behavior at the human/computer interface in terms of three major activities -- production, waiting, and planning. In the personnel records task used in this study, the planning aspect of operator activities was not central and accounted for only a small percent of variance. Additional research is needed to determine if these same three activities characterize human performance in a variety of computer tasks with differential weightings of these dimensions across tasks.

REFERENCES

Beatty, W. F. and Williges, R. C. Embedded performance assessment of system response time in a personnel records task. Blacksburg, Virginia: Virginia Polytechnic Institute and State University, Human Factors Laboratory, Technical Report, October, 1979.

Bitzer, D. L. and Johnson, R. L. PLATO: A computer-based system used in the engineering of education. Proceedings of IEEE, 1971, 59, 960-968.

Carbonell, J. R., Elkind, J. I., and Nickerson, R. S. On the psychological importance of time in a time sharing system. Human Factors, 1968, 10, 135-142.

Engel, S. E. and Granda, R. E. Guidelines for man/display interfaces. Poughkeepsie, New York: IBM, TR 00.2720, December, 1975.

Finkelman, J. M., Wolfe, E. H., and Friend, M. A. Polynomial regression analysis as an alternative to ANOVA for data characterized by lower-order trends. Human Factors, 1977, 99, 279-281.

General Accounting Office. The Navy's computerized pay system is unreliable and inefficient--What went wrong? Washington, D.C.: General Accounting Office, Report to Congress No. FGMSD-80-71, September 26, 1980.

Grossberg, M., Wiesen, R. A. and Yntema, D. B. An experiment on problem solving with delayed computer responses. IEEE Transactions on Systems, Man, and Cybernetics, March, 1976, 219-222.

Hoecker, D. G. and Pew, R. W. A quantitative comparison of SSA interviewing activities with and without computer assistance. In C. K. Bensel (Ed.) Proceedings of the Human Factors Society 23rd Annual Meeting. Santa Monica, California: Human Factors Society, October, 1979, 581-585.

Mason, L. H., Evans, J. E., and Beatty, W. F. Generic data transaction system: Version 2 user's guide. Blacksburg, Virginia: Virginia Polytechnic Institute and State University, Technical Report HFL-79-4/NPRDC-79-3, August, 1979.

Michna, K. R., Laidlow, C. E., and Obermayer, R. W. Source data improvement program (SDIP): Economic analysis of alternative data entry systems. San Diego: Navy Personnel Research and Development Center, January, 1978.

Miller, L. H. A study of man-machine interaction. National computer conference. 1977, 409-421.

Miller, R. B. Response time in man-computer conversational transactions. Fall Joint Computer Conference, 1968, 268-277.

Morfield, M. A. Wiesen, R. A., Grossberg, M. and Yntema, D. B. Initial experiments on the effect of system delay on on-line problem solving. Lexington, Massachusetts: MIT Lincoln Laboratory, Technical Note 1969-5, ESN-TR-158, June, 1969.

Obermayer, R. W. Accuracy and timeliness in large-scale data entry subsystems. In A. S. Neal and R. F. Palasek (Eds.) Proceedings of the 21st annual meeting of the Human Factors Society. Santa Monica, California: The Human Factors Society, October, 1977, 173-177.

Williges, R. C. Automation of performance assessment. San Diego, California: Navy Personnel Research and Development Center, Symposium proceedings: Productivity enhancement: Personnel performance assessment in Navy systems. October, 1977, 153-168.

Williges, R. C. Development and use of research methodologies for complex system/simulation experimentation. In M. J. Moraal and K. F. Krairs (Eds.) Manned systems design preprints. Freiburg, Germany: NATO, September, 1980, 62-102.

APPENDIX A

OPERATOR SATISFACTION RATING SCALE

OPERATOR SATISFACTION RATING SCALE

DIRECTIONS: Circle the appropriate response for the "YES" and "NO" questions.

1. TONE

   a. Did the tone affect your performance?

      Yes No

   b. Use a slash to indicate whether the Tone was OK, Interfering, or Helpful.

```
    +----+----+----+----+----+----+----+----+----+----+
INTERFERING                  OK                   HELPFUL
```

2. SYSTEM RESPONSE TIME

   System Response Time is the time it takes the computer to respond to your commands. It is measured from the time you hit the NEXT key until the time you see the "command arrow."

   a. Did the System Response Time affect your performance?

      Yes No

   b. Use a slash to indicate whether the System Response Time was OK, Too Slow, or Too Fast.

```
    +----+----+----+----+----+----+----+----+----+----+
TOO SLOW                     OK                   TOO FAST
```

3. DYNAMIC DISPLAY RATE

Dynamic Display Rate is the speed with which the computer writes the DATA in a field (such as the Name Field) when you retrieve a record from the file (for example, on a change).

a. Did the Dynamic Display Rate affect your performance?

Yes No

b. Use a slash to indicate whether the Dynamic Display Rate was OK, Too Slow, or Too Fast.

```
  +----+----+----+----+----+----+----+----+----+----+
TOO SLOW                      OK                    TOO FAST
```

4. KEYSTROKE ECHO DELAY

Keystroke Echo Delay is the time it takes the computer to write a character on the display after you have made a keystroke.

a. Did the Keystroke Echo Delay affect your performance?

Yes No

b. Use a slash to indicate whether the Keystroke Echo Delay was OK, Too Long, or Too Short.

```
  +----+----+----+----+----+----+----+----+----+----+
TOO LONG                      OK                    TOO SHORT
```

5. <u>TYPE AHEAD BUFFER LENGTH</u>

Type Ahead Buffer Length is the number of characters you can type ahead of what you can see on the display.

a. Did the length of the Type Ahead Buffer affect your performance?

Yes No

b. Use a slash to indicate whether the Type Ahead Buffer was OK, Too Short, or Too Long.

```
    +----+----+----+----+----+----+----+----+----+----+
TOO SHORT                  OK                  TOO LONG
```

6. <u>OPERATOR SATISFACTION: SPEED</u>

Are you satisfied that the characteristics of this system did not slow down your completion of the task?

```
    +----+----+----+----+----+----+----+----+----+----+
TOTALLY UNSATISFIED                  TOTALLY SATISFIED

THE SYSTEM ALWAYS SLOWED          THE SYSTEM NEVER SLOWED
DOWN MY PERFORMANCE.              DOWN MY PERFORMANCE.
```

7. <u>OPERATOR</u> <u>SATISFACTION</u>: <u>ACCURACY</u>

Are you satisfied that the characteristics of this system did not decrease your accuracy in completing the task?

```
    +----+----+----+----+----+----+----+----+----+----+
TOTALLY UNSATISFIED                                    TOTALLY SATISFIED

THE SYSTEM ALWAYS                                THE SYSTEM NEVER
DECREASED MY ACCURACY.                           DECREASED MY ACCURACY.
```

8. <u>OPERATOR</u> <u>SATISFACTION</u>: <u>OVERALL</u>

Are you satisfied that the characteristics of this system did not interfere with your overall performance?

```
    +----+----+----+----+----+----+----+----+----+----+
TOTALLY UNSATISFIED                                    TOTALLY SATISFIED

THE SYSTEM ALWAYS                                THE SYSTEM NEVER
DECREASED MY PERFORMANCE.                        DECREASED MY PERFORMANCE.
```

APPENDIX B

ANALYSIS OF VARIANCE SUMMARY TABLES
UNIVARIATE ANALYSES

Table B.1
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of INF

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	0.15550	1.27	0.2253
Buffer Length (BL)	1	0.00471	0.54	0.4639
Echo Rate (ER)	1	0.00277	0.32	0.5741
Display Rate (DR)	1	0.00010	0.01	0.9132
System Delay (SD)	1	0.01843	2.10	0.1479
BL^2	1	0.03395	3.87	0.0498
ER^2	1	0.00004	0.01	0.9406
DR^2	1	0.00005	0.01	0.9390
SD^2	1	0.02183	2.49	0.1154
BL*ER	1	0.00000	0.00	0.9877
BL*DR	1	0.01476	1.68	0.1952
BL*SD	1	0.04255	4.85	0.0282
ER*DR	1	0.00075	0.09	0.7699
ER*SD	1	0.01528	1.74	0.1875
DR*SD	1	0.00023	0.03	0.8710
Residual	385	3.37565		
Total	399	3.53115		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned} INF = {} & 0.1673 + 0.0038BL - 0.0029ER - 0.0005DR \\ & - 0.0075SD - 0.0162BL^2 - 0.0006ER^2 - 0.0006DR^2 \\ & + 0.0130SD^2 - 0.0001BL*ER - 0.0075BL*DR \\ & - 0.0128BL*SD + 0.0017ER*DR - 0.0077ER*SD \\ & - 0.0009DR*SD \end{aligned}$$

$R^2 = .044$

Table B.2
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of DSP

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	2.74673	15.58	0.0001
Buffer Length (BL)	1	0.00096	0.08	0.7817
Echo Rate (ER)	1	0.21954	17.44	0.0001
Display Rate (DR)	1	0.00256	0.20	0.6523
System Delay (SD)	1	2.21472	175.91	0.0001
BL^2	1	0.00003	0.00	0.9552
ER^2	1	0.00031	0.03	0.8742
DR^2	1	0.10655	8.46	0.0038
SD^2	1	0.00203	0.16	0.6876
BL*ER	1	0.02625	2.08	0.1496
BL*DR	1	0.04696	3.73	0.0542
BL*SD	1	0.00168	0.13	0.7146
ER*DR	1	0.00446	0.36	0.5516
ER*SD	1	0.11290	8.97	0.0029
DR*SD	1	0.00718	0.61	0.4341
Residual	385	4.84727		
Total	399	7.59400		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned} DSP = {} & 0.2371 + 0.0017BL + 0.0261ER + 0.0028DR \\ & + 0.0831SD - 0.0005BL^2 + 0.0015ER^2 + 0.0288DR^2 \\ & + 0.0039SD^2 + 0.0101BL{*}ER - 0.0135BL{*}DR \\ & - 0.0025BL{*}SD + 0.0041ER{*}DR - 0.0210ER{*}SD \\ & - 0.0054DR{*}SD \end{aligned}$$

$$R^2 = .361$$

Table B.3
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of KBD

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	0.03078	2.26	0.0057
Buffer Length (BL)	1	0.00000	0.00	0.9736
Echo Rate (ER)	1	0.00073	0.76	0.3847
Display Rate (DR)	1	0.00377	3.89	0.0494
System Delay (SD)	1	0.00512	5.27	0.0223
BL^2	1	0.00063	0.66	0.4191
ER^2	1	0.00045	0.47	0.4955
DR^2	1	0.00384	3.95	0.0475
SD^2	1	0.00874	8.99	0.0029
BL*ER	1	0.00272	2.81	0.0948
BL*DR	1	0.00442	4.55	0.0336
BL*SD	1	0.00023	0.24	0.6216
ER*DR	1	0.00003	0.03	0.8537
ER*SD	1	0.00002	0.03	0.8659
DR*SD	1	0.00001	0.02	0.8950
Residual	385	0.37440		
Total	399	0.40518		

SECOND-ORDER POLYNOMIAL REGRESSION

$$
\begin{aligned}
KBD = {} & 0.0281 + .00017BL - 0.0015ER - 0.0034DR \\
& + 0.0040SD + 0.0022BL^2 - 0.0018ER^2 - 0.0054DR^2 \\
& - 0.0082SD^2 - 0.0032BL*ER + 0.0041BL*DR \\
& - 0.0009BL*SD - 0.0003ER*DR - 0.0003ER*SD \\
& - 0.0002DR*SD
\end{aligned}
$$

$$R^2 = .075$$

Table B.4
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of INF/TYP

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	0.10757	2.42	0.0029
Buffer Length (BL)	1	0.00472	1.49	0.2236
Echo Rate (ER)	1	0.01213	3.82	0.0514
Display Rate (DR)	1	0.00411	1.30	0.2556
System Delay (SD)	1	0.03059	9.63	0.0021
BL^2	1	0.00787	2.48	0.1160
ER^2	1	0.00325	1.02	0.3126
DR^2	1	0.01987	6.26	0.0128
SD^2	1	0.00176	0.55	0.4570
BL*ER	1	0.00228	0.72	0.3969
BL*DR	1	0.00151	0.48	0.4908
BL*SD	1	0.00013	0.04	0.8371
ER*DR	1	0.00040	0.13	0.7207
ER*SD	1	0.01422	4.48	0.0350
DR*SD	1	0.00468	1.47	0.2254
Residual	385	1.22301		
Total	399	1.33059		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned} INF/TYP = {} & 0.0498 + 0.0038BL - 0.0061ER + 0.0035DR \\ & - 0.0097SD - 0.0079BL^2 - 0.0050ER^2 - 0.0124DR^2 \\ & - 0.0037SD^2 + 0.0029BL*ER + 0.0024BL*DR \\ & - 0.0007BL*SD + 0.0012ER*DR + 0.0074ER*SD \\ & - 0.0042DR*SD \end{aligned}$$

$$R^2 = .080$$

Table B.5
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of DSP/TYP

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	0.77597	2.75	0.0007
Buffer Length (BL)	1	0.07464	3.71	0.0548
Echo Rate (ER)	1	0.51951	25.82	0.0001
Display Rate (DR)	1	0.00601	0.30	0.5848
System Delay (SD)	1	0.01594	0.79	0.3739
BL^2	1	0.00984	0.49	0.4844
ER^2	1	0.00385	0.19	0.6621
DR^2	1	0.06548	3.25	0.0720
SD^2	1	0.00894	0.44	0.5053
BL*ER	1	0.00442	0.22	0.6395
BL*DR	1	0.05505	2.74	0.0989
BL*SD	1	0.00083	0.04	0.8384
ER*DR	1	0.00000	0.00	0.9846
ER*SD	1	0.00082	0.04	0.8393
DR*SD	1	0.01056	0.52	0.4692
Residual	385	7.74747		
Total	399	8.52345		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned}DSP/TYP = {} & 0.2424 - 0.0152BL + 0.0402ER - 0.0043DR \\ & + 0.0070SD + 0.0037BL^2 - 0.0054ER^2 - 0.0226DR^2 \\ & + 0.0083SD^2 - 0.0041BL*ER + 0.0146BL*DR \\ & + 0.0018BL*SD + 0.0001ER*DR - 0.0017ER*SD \\ & + 0.0064DR*SD\end{aligned}$$

$R^2 = .091$

Table B.6
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of KBD/TYP

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	3.21812	14.25	0.0001
Buffer Length (BL)	1	0.0107	0.67	0.4150
Echo Rate (ER)	1	0.99864	61.90	0.0001
Display Rate (DR)	1	0.00118	0.07	0.7865
System Delay (SD)	1	1.89195	117.28	0.0001
BL^2	1	0.00052	0.03	0.8570
ER^2	1	0.01680	1.04	0.3081
DR^2	1	0.01951	1.21	0.2719
SD^2	1	0.02314	1.43	0.2317
BL*ER	1	0.03762	2.33	0.1275
BL*DR	1	0.00000	0.00	0.9881
BL*SD	1	0.06015	3.73	0.0542
ER*DR	1	0.01243	0.77	0.3806
ER*SD	1	0.14006	8.68	0.0034
DR*SD	1	0.00531	0.33	0.5662
Residual	385	6.21102		
Total	399	9.42914		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned} KBD/TYP = {} & 0.2751 + 0.0057BL - 0.0558ER + 0.0019DR \\ & - 0.0768SD - 0.0020BL^2 + 0.0114ER^2 + 0.0123DR^2 \\ & - 0.0134SD^2 - 0.0121BL*ER - 0.0001BL*DR \\ & + 0.0153BL*SD - 0.0069ER*DR + 0.0233ER*SD \\ & + 0.0045DR*SD \end{aligned}$$

$$R^2 = .341$$

Table B.7
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of TRATE

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	0.01841	43.60	0.0001
Buffer Length (BL)	1	0.00030	10.06	0.0016
Echo Rate (ER)	1	0.01603	531.64	0.0001
Display Rate (DR)	1	0.00014	4.69	0.0309
System Delay (SD)	1	0.00000	0.01	0.9240
BL^2	1	0.00012	4.14	0.0426
ER^2	1	0.00041	13.90	0.0002
DR^2	1	0.00000	0.00	0.9543
SD^2	1	0.00001	0.34	0.5579
BL*ER	1	0.00049	16.54	0.0001
BL*DR	1	0.00013	4.50	0.0345
BL*SD	1	0.00019	6.45	0.0115
ER*DR	1	0.00041	13.70	0.0002
ER*SD	1	0.00000	0.33	0.5666
DR*SD	1	0.00012	4.17	0.0419
Residual	385	0.01161		
Total	399	0.03002		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned} TRATE = {} & 0.020 + 0.000BL - 0.007ER + 0.000DR \\ & - 0.0000SD - 0.000BL^2 + 0.001ER^2 - 0.0000DR^2 \\ & + 0.000SD^2 + 0.001BL*ER - 0.000BL*DR \\ & - 0.000BL*SD - 0.001ER*DR - 0.000ER*SD \\ & - 0.000DR*SD \end{aligned}$$

$R^2 = .613$

Table B.8
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of FE/URT

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	305970.28	9.32	0.0001
Buffer Length (BL)	1	145.03	0.06	0.8037
Echo Rate (ER)	1	552.28	0.24	0.6278
Display Rate (DR)	1	6907.27	2.95	0.0869
System Delay (SD)	1	228921.60	97.60	0.0001
BL^2	1	37.09	0.02	0.9013
ER^2	1	3969.50	1.69	0.1941
DR^2	1	5626.22	2.40	0.1222
SD^2	1	40835.15	17.41	0.0001
BL*ER	1	6045.06	2.58	0.1092
BL*DR	1	1914.06	0.82	0.3669
BL*SD	1	1207.56	0.51	0.4735
ER*DR	1	2013.76	0.86	0.3547
ER*SD	1	968.76	0.41	0.5208
DR*SD	1	6826.89	2.91	0.0888
Residual	385	902983.09		
Total	399	1208953.37		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned} FE/URT = {} & 44.924 + 0.673BL - 1.313ER - 4.646DR \\ & - 26.747SD + 0.531BL^2 + 5.563ER^2 + 6.626DR^2 \\ & + 17.864SD^2 - 4.859BL*ER - 2.734BL*DR \\ & + 2.171BL*SD + 2.804ER*DR - 1.945ER*SD \\ & + 5.164DR*SD \end{aligned}$$

$$R^2 = .253$$

Table B.9
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of NF/URT

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	38212.84	2.45	0.0026
Buffer Length (BL)	1	1416.73	1.27	0.2603
Echo Rate (ER)	1	2795.35	2.51	0.1141
Display Rate (DR)	1	1824.75	1.64	0.2015
System Delay (SD)	1	18736.47	16.81	0.0001
BL^2	1	682.35	0.61	0.4342
ER^2	1	772.54	0.69	0.4058
DR^2	1	1509.22	1.36	0.2451
SD^2	1	6166.35	5.53	0.0192
BL*ER	1	9.00	0.01	0.9284
BL*DR	1	107.64	0.10	0.7562
BL*SD	1	222.76	0.21	0.6508
ER*DR	1	1827.56	1.64	0.2012
ER*SD	1	189.06	0.17	0.6807
DR*SD	1	1947.01	1.75	0.1871
Residual	385	429149.19		
Total	399	467362.04		

SECOND-ORDER POLYNOMIAL REGRESSION

$$
\begin{aligned}
NF/URT = {} & 51.508 - 2.104BL + 2.955ER - 2.388DR \\
& - 7.652SD - 2.310BL^2 + 2.456ER^2 - 3.436DR^2 \\
& + 6.942SD^2 + 0.187BL*ER - 0.648BL*DR \\
& + 0.945BL*SD + 2.671ER*DR - 0.859ER*SD \\
& + 2.757DR*SD
\end{aligned}
$$

$R^2 = .081$

Table B.10
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of FE/RT

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	4247357.34	23.04	0.0001
Buffer Length (BL)	1	45327.41	3.44	0.0643
Echo Rate (ER)	1	5749.53	0.44	0.5091
Display Rate (DR)	1	62538.16	4.75	0.0299
System Delay (SD)	1	3860652.69	293.22	0.0001
BL^2	1	1440.58	0.11	0.7405
ER^2	1	14990.31	1.14	0.2862
DR^2	1	7424.57	0.56	0.4536
SD^2	1	108013.11	8.20	0.0044
BL*ER	1	27163.16	2.06	0.1517
BL*DR	1	71.19	0.01	0.9414
BL*SD	1	46359.47	3.52	0.0613
ER*DR	1	201.28	0.02	0.9017
ER*SD	1	1985.81	0.15	0.6980
DR*SD	1	65440.03	4.97	0.0264
Residual	385	5069023.36		
Total	399	9316380.71		

SECOND-ORDER POLYNOMIAL REGRESSION

$$FE/RT = 88.889 + 11.901BL - 4.238ER + 13.980DR + 109.842SD - 3.361BL^2 - 10.832ER^2 + 7.610DR^2 + 29.054SD^2 - 10.300BL*ER - 0.527BL*DR + 13.457BL*SD + 0.886ER*DR - 2.785ER*SD + 15.988DR*SD$$

$$R^2 = .455$$

Table B.11
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of NF/RT

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	3316465.67	19.78	0.0001
Buffer Length (BL)	1	23215.30	1.94	0.1646
Echo Rate (ER)	1	22553.15	1.88	0.1707
Display Rate (DR)	1	12233.77	1.02	0.3127
System Delay (SD)	1	3024378.77	252.59	0.0001
BL^2	1	162.70	0.01	0.9079
ER^2	1	655.53	0.06	0.8145
DR^2	1	47.07	0.00	0.9494
SD^2	1	148639.03	12.41	0.0005
BL*ER	1	36409.41	3.04	0.0820
BL*DR	1	190.78	0.02	0.8996
BL*SD	1	19757.81	1.65	0.1997
ER*DR	1	1093.12	0.09	0.7627
ER*SD	1	12953.28	1.08	0.2989
DR*SD	1	14175.67	1.18	0.2772
Residual	385	4609797.72		
Total	399	7926263.39		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned} NF/RT = {} & 65.470 + 8.517BL - 8.395ER + 6.183DR \\ & + 97.220SD + 1.120BL^2 - 2.271ER^2 - 0.614DR^2 \\ & + 34.083SD^2 - 11.925BL{*}ER + 0.863BL{*}DR \\ & + 3.785BL{*}SD - 2.066ER{*}DR - 7.113ER{*}SD \\ & + 7.441DR{*}SD \end{aligned}$$

$$R^2 = .418$$

Table B.12
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of RDRSP

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	10810.53	15.27	0.0001
Buffer Length (BL)	1	51.89	1.03	0.3117
Echo Rate (ER)	1	8.88	0.18	0.6754
Display Rate (DR)	1	6.10	0.12	0.7284
System Delay (SD)	1	10075.54	199.26	0.0001
BL^2	1	168.90	3.34	0.0685
ER^2	1	114.38	2.26	0.1334
DR^2	1	92.77	1.84	0.1763
SD^2	1	6.58	0.13	0.7184
BL*ER	1	59.09	1.17	0.2803
BL*DR	1	29.56	0.58	0.4449
BL*SD	1	75.47	1.49	0.2226
ER*DR	1	103.78	2.05	0.1528
ER*SD	1	17.53	0.35	0.5563
DR*SD	1	0.00	0.00	0.9930
Residual	385	19467.21		
Total	399	30277.75		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned} RDRSP = {} & 3.799 + 0.402BL + 0.166ER + 0.138DR \\ & + 5.611SD - 1.148BL^2 - 0.945ER^2 - 0.851DR^2 \\ & + 0.226SD^2 - 0.480BL*ER - 0.339BL*DR \\ & + 0.542BL*SD - 0.636ER*DR + 0.261ER*SD \\ & - 0.003DR*SD \end{aligned}$$

$R^2 = .357$

Table B.13
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of CHER

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	226.14	1.86	0.0297
Buffer Length (BL)	1	15.63	1.80	0.1810
Echo Rate (ER)	1	101.42	11.65	0.0007
Display Rate (DR)	1	9.75	1.12	0.2905
System Delay (SD)	1	1.25	0.14	0.7049
BL^2	1	22.95	2.64	0.1053
ER^2	1	32.19	3.70	0.0552
DR^2	1	15.25	1.75	0.1864
SD^2	1	4.43	0.51	0.4759
BL*ER	1	3.75	0.43	0.5118
BL*DR	1	2.06	0.24	0.6264
BL*SD	1	0.66	0.08	0.7832
ER*DR	1	5.94	0.68	0.4093
ER*SD	1	10.16	1.17	0.2807
DR*SD	1	0.66	0.08	0.7832
Residual	385	3351.75		
Total	399	3577.89		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned} CHER = {} & 2.814 - 0.221BL + 0.562ER + 0.174DR \\ & + 0.062SD - 0.423BL^2 - 0.501ER^2 - 0.345DR^2 \\ & + 0.186SD^2 + 0.121BL*ER + 0.089BL*DR \\ & + 0.050BL*SD - 0.152ER*DR + 0.199ER*SD \\ & - 0.050DR*SD \end{aligned}$$

$R^2 = .063$

Table B.14
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of CKT

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	2876003.23	1.97	0.0188
Buffer Length (BL)	1	100836.95	0.97	0.3257
Echo Rate (ER)	1	144235.99	1.39	0.2399
Display Rate (DR)	1	1177252.43	11.31	0.0008
System Delay (SD)	1	71005.53	0.68	0.4094
BL^2	1	19272.11	0.18	0.6676
ER^2	1	79005.14	0.76	0.3844
DR^2	1	26.58	0.00	0.9871
SD^2	1	54919.20	0.53	0.4681
BL*ER	1	195750.94	1.88	0.1711
BL*DR	1	114793.91	1.10	0.2944
BL*SD	1	506143.31	4.86	0.0281
ER*DR	1	16528.31	0.16	0.6905
ER*SD	1	65248.31	0.63	0.4291
DR*SD	1	330984.47	3.18	0.0754
Residual	385	40088219.87		
Total	399	42964223.11		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned} CKT = {} & 152.69 - 17.75BL + 21.23ER - 60.65DR \\ & - 14.89SD + 12.26BL^2 + 24.84ER^2 - 0.46DR^2 \\ & + 20.71SD^2 - 27.65BL*ER + 21.17BL*DR \\ & + 44.46BL*SD - 8.03ER*DR - 15.96ER*SD \\ & + 35.95DR*SD \end{aligned}$$

$$R^2 = .066$$

Table B.15
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of TONR

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	260.86	3.58	0.0001
Buffer Length (BL)	1	0.07	0.01	0.9032
Echo Rate (ER)	1	118.37	22.73	0.0001
Display Rate (DR)	1	22.05	4.23	0.0403
System Delay (SD)	1	8.76	1.68	0.1953
BL^2	1	4.20	0.81	0.3696
ER^2	1	17.40	3.34	0.0684
DR^2	1	1.80	0.35	0.5566
SD^2	1	4.80	0.92	0.3372
BL*ER	1	10.56	2.03	0.1553
BL*DR	1	10.56	2.03	0.1553
BL*SD	1	33.60	6.35	0.0122
ER*DR	1	5.06	0.30	0.5842
ER*SD	1	1.56	0.97	0.3248
DR*SD	1	22.56	4.33	0.0381
Residual	385	2005.49		
Total	399	2266.36		

SECOND-ORDER POLYNOMIAL REGRESSION

$$
\begin{aligned}
TONR = {} & 5.910 + 0.015BL - 0.608ER + 0.262DR \\
& - 0.165SD + 0.181BL^2 + 0.368ER^2 + 0.118DR^2 \\
& - 0.193SD^2 - 0.203BL*ER - 0.203BL*DR \\
& - 0.359BL*SD - 0.078ER*DR + 0.140ER*SD \\
& - 0.296DR*SD
\end{aligned}
$$

$$R^2 = .115$$

Table B.16
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of SDR

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	789.52	30.95	0.0001
Buffer Length (BL)	1	0.09	0.05	0.8149
Echo Rate (ER)	1	20.00	10.98	0.0010
Display Rate (DR)	1	1.33	0.73	0.3921
System Delay (SD)	1	693.83	380.81	0.0001
BL^2	1	4.50	2.47	0.1170
ER^2	1	8.00	4.39	0.0368
DR^2	1	8.00	4.39	0.0368
SD^2	1	17.99	9.88	0.0018
BL*ER	1	4.00	2.20	0.1392
BL*DR	1	1.00	0.55	0.4592
BL*SD	1	2.25	1.23	0.2671
ER*DR	1	16.00	8.78	0.0032
ER*SD	1	6.25	3.43	0.0648
DR*SD	1	6.25	3.43	0.0648
Residual	385	701.47		
Total	399	1491.00		

SECOND-ORDER POLYNOMIAL REGRESSION

$$SDR = 2.100 + 0.017BL - 0.250ER + 0.064DR - 1.472SD + 0.187BL^2 + 0.249ER^2 + 0.249DR^2 + 0.375SD^2 - 0.125BL*ER - 0.062BL*DR + 0.093BL*SD + 0.250ER*DR + 0.156ER*SD - 0.156DR*SD$$

$R^2 = .529$

Table B.17
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of DSPR

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	249.96	4.54	0.0001
Buffer Length (BL)	1	1.28	0.33	0.5679
Echo Rate (ER)	1	3.89	0.99	0.3201
Display Rate (DR)	1	26.05	6.63	0.0104
System Delay (SD)	1	28.22	7.18	0.0077
BL^2	1	49.98	12.72	0.0004
ER^2	1	84.51	21.49	0.0001
DR^2	1	0.49	0.13	0.7219
SD^2	1	1.99	0.51	0.4764
BL*ER	1	12.25	3.12	0.0784
BL*DR	1	36.00	9.15	0.0026
BL*SD	1	0.00	0.00	1.0000
ER*DR	1	1.00	0.25	0.6144
ER*SD	1	4.00	1.02	0.3138
DR*SD	1	0.25	0.06	0.8011
Residual	385	1514.03		
Total	399	1764.00		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned} DSPR = {} & 4.200 + 0.063BL - 0.1101ER - 0.285DR \\ & - 0.296SD - 0.625BL^2 + 0.812ER^2 + 0.062DR^2 \\ & + 0.124SD^2 + 0.213BL*ER - 0.375BL*DR \\ & + 0.000BL*SD - 0.062ER*DR + 0.125ER*SD \\ & + 0.031DR*SD \end{aligned}$$

$R^2 = .141$

Table B.18
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of ERR

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	732.03	28.69	0.0001
Buffer Length (BL)	1	4.66	2.56	0.1106
Echo Rate (ER)	1	6543.20	358.93	0.0001
Display Rate (DR)	1	4.66	2.56	0.1106
System Delay (SD)	1	12.63	6.93	0.0088
BL^2	1	0.08	0.04	0.8349
ER^2	1	14.58	8.00	0.0049
DR^2	1	0.08	0.04	0.8349
SD^2	1	27.37	15.02	0.0001
BL*ER	1	1.00	0.55	0.4593
BL*DR	1	9.00	4.94	0.0269
BL*SD	1	0.25	0.14	0.7113
ER*DR	1	1.00	0.55	0.4593
ER*SD	1	2.25	1.23	0.2672
DR*SD	1	0.25	0.14	0.7113
Residual	385	701.72		
Total	399	1433.76		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned} ERR = {} & 2.660 - 0.120BL - 1.429ER - 0.120DR \\ & - 0.198SD + 0.024BL^2 + 0.337ER^2 + 0.024DR^2 \\ & + 0.462SD^2 - 0.062BL*ER - 0.187BL*DR \\ & - 0.031BL*SD - 0.062ER*DR - 0.093ER*SD \\ & + 0.031DR*SD \end{aligned}$$

$R^2 = .510$

Table B.19
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of BLR

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	640.64	22.99	0.0001
Buffer Length (BL)	1	98.94	49.71	0.0001
Echo Rate (ER)	1	298.87	150.14	0.0001
Display Rate (DR)	1	0.03	0.02	0.8957
System Delay (SD)	1	26.61	13.37	0.0003
BL^2	1	25.90	13.03	0.0003
ER^2	1	58.34	29.29	0.0001
DR^2	1	3.92	1.97	0.1616
SD^2	1	48.01	24.12	0.0001
BL*ER	1	72.25	36.30	0.0001
BL*DR	1	0.25	0.13	0.7232
BL*SD	1	1.00	0.50	0.4789
ER*DR	1	0.00	0.00	1.0000
ER*SD	1	6.25	3.14	0.0772
DR*SD	1	0.25	0.13	0.7232
Residual	385	766.39		
Total	399	1407.04		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned} BLR = {} & 2.870 + 0.556BL - 0.966ER + 0.101DR \\ & - 0.288SD - 0.450BL^2 + 0.675ER^2 + 0.174DR^2 \\ & + 0.612SD^2 + 0.531BL*ER - 0.031BL*DR \\ & - 0.062BL*SD + 0.000ER*DR - 0.156ER*SD \\ & - 0.031DR*SD \end{aligned}$$

$R^2 = .455$

Table B.20
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of SPEED

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	2016.20	38.89	0.0001
Buffer Length (BL)	1	20.98	5.67	0.0178
Echo Rate (ER)	1	1038.87	280.57	0.0001
Display Rate (DR)	1	8.99	2.43	0.1199
System Delay (SD)	1	486.36	131.35	0.0001
BL^2	1	0.18	0.05	0.8268
ER^2	1	106.62	28.77	0.0001
DR^2	1	15.68	4.23	0.0404
SD^2	1	137.74	37.20	0.0001
BL*ER	1	4.00	1.08	0.2993
BL*DR	1	12.25	3.31	0.0697
BL*SD	1	6.25	1.69	0.1947
ER*DR	1	9.00	2.43	0.1198
ER*SD	1	169.00	45.64	0.0001
DR*SD	1	0.25	0.07	0.7951
Residual	385	1425.55		
Total	399	3441.76		

SECOND-ORDER POLYNOMIAL REGRESSION

$$
\begin{aligned}
SPEED = {} & 1.790 + 0.256BL - 1.801ER - 0.167DR \\
& - 1.232SD + 0.037BL^2 + 0.912ER^2 + 0.349DR^2 \\
& + 1.037SD^2 + 0.125BL*ER - 0.218BL*DR \\
& - 0.156BL*SD + 0.187ER*DR + 0.812ER*SD \\
& + 0.031DR*SD
\end{aligned}
$$

$R^2 = .585$

Table B.21
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of ACCUR

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	1579.03	23.78	0.0001
Buffer Length (BL)	1	14.86	3.13	0.0775
Echo Rate (ER)	1	935.71	197.27	0.0775
Display Rate (DR)	1	4.36	0.92	0.3380
System Delay (SD)	1	232.64	49.05	0.0001
BL^2	1	0.04	0.01	0.9234
ER^2	1	108.07	22.77	0.0001
DR^2	1	3.64	0.77	0.3819
SD^2	1	93.81	19.78	0.0001
BL*ER	1	0.06	0.01	0.9087
BL*DR	1	18.06	3.81	0.0517
BL*SD	1	27.56	5.81	0.0164
ER*DR	1	27.56	5.81	0.0164
ER*SD	1	105.06	22.15	0.0001
DR*SD	1	7.56	1.59	0.2075
Residual	385	1826.20		
Total	399	3405.24		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned} ACCUR = {} & 2.830 + 0.215BL - 1.710ER - 0.116DR \\ & - 0.852SD + 0.019BL^2 + 0.918ER^2 + 0.168DR^2 \\ & + 0.856SD^2 + 0.015BL*ER - 0.265BL*DR \\ & - 0.323BL*SD + 0.328ER*DR + 0.640ER*SD \\ & + 0.171DR*SD \end{aligned}$$

$$R^2 = .463$$

Table B.22
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of OVER

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	1734.38	29.67	0.0001
Buffer Length (BL)	1	11.61	2.78	0.0961
Echo Rate (ER)	1	1007.80	241.39	0.0001
Display Rate (DR)	1	29.80	7.14	0.0079
System Delay (SD)	1	269.26	64.49	0.0001
BL^2	1	0.00	0.00	0.9736
ER^2	1	146.24	35.01	0.0001
DR^2	1	8.40	2.01	0.1571
SD^2	1	99.36	23.80	0.0001
BL*ER	1	3.06	0.73	0.3923
BL*DR	1	3.06	0.73	0.3923
BL*SD	1	22.56	5.40	0.0206
ER*DR	1	27.56	6.60	0.0106
ER*SD	1	105.06	25.16	0.0001
DR*SD	1	0.56	0.13	0.7138
Residual	385	1607.37		
Total	399	3341.76		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned} OVER = {} & 2.390 + 0.190BL - 1.774ER - 0.305DR \\ & - 0.917SD + 0.005BL^2 + 1.068ER^2 + 0.256DR^2 \\ & + 0.381SD^2 + 0.109BL{*}ER - 0.109BL{*}DR \\ & - 0.029BL{*}SD + 0.328ER{*}DR + 0.640ER{*}SD \\ & + 0.046DR{*}SD \end{aligned}$$

$R^2 = .519$

APPENDIX C

ANALYSIS OF VARIANCE SUMMARY TABLES
MULTIVARIATE ANALYSES

Table C.1
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of PRODUCTION

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	248.88	45.60	0.0001
Buffer Length (BL)	1	1.35	3.48	0.0630
Echo Rate (ER)	1	105.71	271.14	0.0001
Display Rate (DR)	1	0.75	1.93	0.1654
System Delay (SD)	1	116.34	298.39	0.0001
BL^2	1	0.06	0.16	0.6889
ER^2	1	11.31	29.02	0.0001
DR^2	1	0.64	1.65	0.1996
SD^2	1	4.76	12.23	0.0005
BL*ER	1	0.77	2.00	0.1582
BL*DR	1	1.05	2.71	0.1008
BL*SD	1	1.12	2.90	0.0896
ER*DR	1	0.55	1.41	0.2356
ER*SD	1	4.33	11.12	0.0009
DR*SD	1	0.07	0.20	0.6540
Residual	385	150.11		
Total	399	399.00		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned}\text{PRODUCTION} = &- 0.4313 + 0.0650BL - 0.5747ER - 0.0485DR \\ &- 0.6029SD - 0.0221BL^2 + 0.2973ER^2 + 0.0709DR^2 \\ &+ 0.1930SD^2 + 0.0551BL{*}ER - 0.0641BL{*}DR \\ &- 0.0664BL{*}SD + 0.0463ER{*}DR + 0.1301ER{*}SD \\ &- 0.0175DR{*}SD\end{aligned}$$

$R^2 = .623$

Table C.2
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of WAITING

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	206.62	29.54	0.0001
Buffer Length (BL)	1	5.38	10.79	0.0011
Echo Rate (ER)	1	91.66	183.45	0.0001
Display Rate (DR)	1	2.21	4.44	0.0358
System Delay (SD)	1	98.02	196.17	0.0001
BL^2	1	0.76	1.53	0.2169
ER^2	1	2.25	4.52	0.0342
DR^2	1	0.39	0.79	0.3739
SD^2	1	0.71	1.43	0.2323
BL*ER	1	0.37	0.76	0.3848
BL*DR	1	1.95	3.91	0.0488
BL*SD	1	0.94	1.88	0.1706
ER*DR	1	1.40	2.81	0.0944
ER*SD	1	0.12	0.25	0.6193
DR*SD	1	0.39	0.78	0.3770
Residual	335	192.37		
Total	399	399.00		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned} \text{WAITING} = &- 0.1487 + 0.1297BL - 0.5352ER + 0.0832DR \\ &+ 0.5534SD - 0.0773BL^2 + 0.1328ER^2 + 0.0556DR^2 \\ &+ 0.0747SD^2 + 0.0384BL{*}ER - 0.0873BL{*}DR \\ &- 0.0606BL{*}SD - 0.0740ER{*}DR + 0.0219ER{*}SD \\ &- 0.0390DR{*}SD \end{aligned}$$

$R^2 = .517$

Table C.3
Analysis of Variance Summary Table of Second-Order, Polynomial Regression of PLANNING

ANOVA SUMMARY TABLE

Source	df	SS	F	p
Regression	(14)	64.92	5.34	0.0001
Buffer Length (BL)	1	0.26	0.31	0.5786
Echo Rate (ER)	1	17.10	19.71	0.0001
Display Rate (DR)	1	1.58	1.83	0.1769
System Delay (SD)	1	22.46	25.89	0.0001
BL^2	1	0.16	0.19	0.6622
ER^2	1	1.36	1.57	0.2113
DR^2	1	0.13	0.15	0.6945
SD^2	1	16.78	19.34	0.0001
BL*ER	1	0.05	0.06	0.8003
BL*DR	1	0.03	0.04	0.8329
BL*SD	1	0.72	0.84	0.3597
ER*DR	1	0.75	0.87	0.3502
ER*SD	1	0.29	0.34	0.5577
DR*SD	1	3.17	3.66	0.0566
Residual	385	334.07		
Total	399	399.00		

SECOND-ORDER POLYNOMIAL REGRESSION

$$\begin{aligned} PLANNING = &- 0.4268 + 0.028BL - 0.231ER - 0.070DR \\ &+ 0.264SD + 0.036BL^2 + 0.103ER^2 + 0.032DR^2 \\ &+ 0.362SD^2 + 0.014BL*ER + 0.012BL*DR \\ &+ 0.053BL*SD + 0.054ER*DR - 0.034ER*SD \\ &+ 0.111DR*SD \end{aligned}$$

$R^2 = .163$